Carabid beetle (Coleoptera: Carabidae) seasonal occurrence and species composition in northern Montana cropping systems

by Carin Anne Miller

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Entomology

Montana State University



Abstract:
Carabid beetles (Coleoptera: Carabidae) are important natural enemies in agricultural ecosystems. Species composition and seasonal occurrence of carabid beetles in cropping systems were examined in 1998 and 1999 in experimental plots near Havre, Montana. The experiment was designed to compare two tillage systems, conventional and no-till, and treatments within crop rotations: fallow, CRP (Conservation Reserve Program), spring wheat, pea, sunflower, and yellow mustard. Pitfall traps were used to collect carabid beetles in the field for six 7-day sampling periods in 1998, and five 7-day sampling periods in 1999. Forty-five and thirty eight species were collected in 1998 and 1999, respectively. Data were analyzed using a repeated measures analysis of variance and analysis of variance by date. Analyses of total carabids showed a significant date by crop effect, with greater carabid activity occurring in yellow mustard and sunflower in June through August sample dates. Analyses performed on Harpalus fuscipalpis and Amara littoralis found an association with yellow mustard, suggesting that these species were crop type specialists. Amara thoracica and Harpalus paratus activity were closely associated with sunflower. Other species such as Microlestes linearis, Calosoma lepidum, Harpalus reversus, and Amara obesa. exhibited no strong association with a particular crop. Differences between tillage systems were present in 1999 but not in 1998. Responses of individual carabid species to tillage systems varied; for instance, M. linearis activity was consistently greater in tilled plots.

# CARABID BEETLE (COLEOPTERA: CARABIDAE) SEASONAL OCCURRENCE AND SPECIES COMPOSITION IN NORTHERN MONTANA CROPPING SYSTEMS

by

Carin Anne Miller

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Entomology

MONTANA STATE UNIVERSITY
Bozeman, Montana

December 2000

APPROVAL

of a thesis submitted by

Carin Anne Miller

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

Sue L. Blodgett _____ (Signature) 1 Dec 2000 (Date)

Approved for the Department of Entomology

Gregory D. Johnson _____ (Signature) 11-30-00 (Date)

Approved for the College of Graduate Studies

Bruce R. McLeod _____ (Signature) 12-4-00 (Date)

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library.

If I have indicated my intention to copyright this thesis by including a copyright notice page, copying is allowable only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright Law. Requests for permission for extended quotation from or reproduction of this thesis in whole or parts may be granted only by the copyright holder.

Signature Carrie B Miller

Date 4 December 2000

## ACKNOWLEDGMENTS

First I would like to thank my major advisor, Dr. Sue Blodgett, for helping me through every step of my degree and this thesis. Her willingness to discuss ideas and give advice was invaluable and I can't thank her enough. I would also like to thank the other member of my committee, Drs. Greg Johnson, Michael Ivie, and Perry Miller. Dr. Greg Johnson also played an important role in my education as department head. Without his help, I would not be completing this degree. Dr. Michael Ivie provided many hours of help with identification of species and discussing ideas about this project.

I would like to thank Patricia Denke for her assistance and uncanny ability to locate resources when I needed them most. Amy Webb and Jen Demoney were excellent assistants in the field and in the lab and deserve special thanks for working in less than desirable conditions in the field. Marni Rolston also provided assistance in the field and I thank her for her company on many long drives to our field site.

The following people worked in the lab sorting samples and identifying specimens and this project would not have been completed without their help: Megan Gibson, Amanda Hay, Jeff Johnston, , Kenny Keever, Brian Story, Kelly Krenzelok, Ruth O'Neill and Yu-Ying Wang.

Andy Lenssen, Gregg Carlson, and Brad Gregoire all played important roles in keeping the Sustainable Pest Management project running smoothly. I would also like to thank Mark and Nancy Peterson of Mark Peterson Grain and Cattle, Inc. for providing the land needed for this study site. I am indebted to Danny Shpeley of the University of Alberta, Edmonton for his identifications of specimens in the genus *Harpalus*. Finally, I would like to thank my family and friends for all of their support and kindness throughout my education. This would not have been possible without their help.

TABLE OF CONTENTS

TABLE OF CONTENTS – CONTINUED

# LIST OF TABLES

# LIST OF FIGURES

# ABSTRACT

Carabid beetles (Coleoptera: Carabidae) are important natural enemies in agricultural ecosystems. Species composition and seasonal occurrence of carabid beetles in cropping systems were examined in 1998 and 1999 in experimental plots near Havre, Montana. The experiment was designed to compare two tillage systems, conventional and no-till, and treatments within crop rotations: fallow, CRP (Conservation Reserve Program), spring wheat, pea, sunflower, and yellow mustard. Pitfall traps were used to collect carabid beetles in the field for six 7-day sampling periods in 1998, and five 7-day sampling periods in 1999. Forty-five and thirty eight species were collected in 1998 and 1999, respectively. Data were analyzed using a repeated measures analysis of variance and analysis of variance by date. Analyses of total carabids showed a significant date by crop effect, with greater carabid activity occurring in yellow mustard and sunflower in June through August sample dates. Analyses performed on *Harpalus fuscipalpis* and *Amara littoralis* found an association with yellow mustard, suggesting that these species were crop type specialists. *Amara thoracica* and *Harpalus paratus* activity were closely associated with sunflower. Other species such as *Microlestes linearis*, *Calosoma lepidum*, *Harpalus reversus*, and *Amara obesa*. exhibited no strong association with a particular crop. Differences between tillage systems were present in 1999 but not in 1998. Responses of individual carabid species to tillage systems varied; for instance, *M. linearis* activity was consistently greater in tilled plots.

# CHAPTER 1

# LITERATURE REVIEW

Carabid beetles, also known as ground beetles, form the family Carabidae, the third largest family in the order Coleoptera. They are an extremely diverse group, inhabiting practically all habitat and ecosystem types (Lövei and Sunderland 1996). They have been identified as important natural enemies because they prey on a multitude of pests including insects and weed seeds. For the most part, carabids do not fall in the category of insects suitable for classical biological control due to their generalist predatory habits. However, several studies indicate that increased numbers of carabids and other generalist predators such as spiders can effectively keep pest populations in check (Edwards et al. 1979, Edwards and George 1981, Floate et al. 1990, Lövei and Sunderland 1996). Information will be presented on the life history of carabids, habitat choice, predatory behavior, and effects of tillage and crop type on carabids.

## Life History

In general, carabids develop from egg to adult, reproduce, and then die in less than one year. However, there are exceptions to this rule, with some adults living more than one year. Females lay eggs singly or in small to large batches. Sometimes they are

laid in crevices in the soil, or in an excavated chamber prepared by the female, complete with a cache of seeds for the emerging larvae (Ball 1968, Luff 1987, Lövei and Sunderland 1996).

The majority of larvae are free living and campodeiform typically undergoing two to three instars before pupating in a pupal chamber in the soil. In many species, the larvae (second or third instar) undergo diapause, either winter (hibernation) or summer (aestivation).

Some adult carabids have a life span ranging from two-four years (Ball 1968). The longevity of adults depends on environmental conditions and the amount of available food. It is possible for some adults to reproduce more than once during their lifespan.

Many attempts to place carabid beetles into seasonal activity and reproduction categories have been made. Historically, carabids have been separated into two groups: spring breeders or autumn breeders (den Boer and den Boer-Daanje 1990). However, more recent studies have shown that carabid beetles can fall into many different categories, including species with flexible breeding periods and species that require more than one year to develop (Luff 1987, den Boer and den Boer-Daanje 1990, Dülge 1994, Makarov 1994, Fadl and Purvis 1998).

The majority of common carabid species found in agricultural fields are nocturnal (Luff 1987). However, the development of time-sorting pitfall traps has enabled researchers to study diurnal versus nocturnal activity (Blumberg and Crossley 1988, Kegel 1990). Kegel (1990) found that daytime activity is positively correlated with soil temperature in diurnal species and negatively in nocturnal species. Nocturnal species

seem to have high moisture requirements, conditions that favor activity at night rather than daytime when humidity is typically lower (Thiele 1977). Carabids are able to adapt to a variety of habitats due to their flexibility in life cycle and daily activity.

## Carabid Beetle Impacts on Agroecosystems

Carabid beetles are voracious feeders, consuming up to 3 times their body weight daily. The majority of carabid species are generalist predators, eating both animal and plant material. Some attempts have been made to try and categorize species into carnivores, herbivores, or omnivores, but the majority of species are opportunistic, feeding on whatever is available in abundance in their habitat (Thiele 1977, Luff 1987, Lövei and Sunderland 1996). Some are specialists, such as many species in the genus Calosoma which specialize on lepidoptera larvae (Thiele 1977). Others are morphologically specialized for a certain prey type. For example, members of the tribe Cychrini have a narrow pronotum and specialized mandibles which enable them to eat snails (Thiele 1977). However, the morphology of most species suggests that prey choice is driven by what is available, not by biological specialization (Thiele 1977, Luff 1987, Evans 1994).

Morphological studies are based on an examination of an organism's body plan in order to determine habitat and/or prey specialization. The size and shape of the mandibles and the musculature associated with the mandibles can help determine whether or not the animal crushes or pulverizes its prey, or uses the mandibles to tear and cut (Evans 1994).

The morphology of the digestive tract, particularly the proventriculus, can be used as an indicator of diet (Forsythe 1982). If there is a smooth surface, the organism most likely digests most of its food extra-orally and takes up the resulting liquid. A proventriculus with a grinding surface made up of proventricular teeth, on the other hand, is equipped to handle harder substances such as chitinous body parts of insects and plant material such as hard seed coats (Forsythe 1982).

Most carabid species are nocturnal and rely on a randomized search pattern combined with visual and chemical cues to locate prey (Luff 1987, Lövei and Sunderland 1996). While it has been observed that a few species will climb plants when hunting, most stay on the ground (Forsythe 1982, Luff 1987, Lövei and Sunderland 1996). When a prey item is located, search behavior in that area intensifies for a certain amount of time after consumption before the beetle gives up and resumes the random search behavior (Lövei and Sunderland 1996).

The combination of a voracious appetite, opportunistic feeding behavior, and mobility makes carabid beetles effective and important natural enemies in agroecosystems. In recent years, the role of natural enemies in biological control has become more important, although the carabid species complex is often overlooked. Biological control has focused on classical biological control systems, defined as "the importation and establishment of exotic natural enemies for control of pests (usually exotic)" (DeBach 1964, Bugg and Pickett 1998). Typically, this involves the importation of one specific predator to control one pest. Classical biological control systems are based on knowledge of the population dynamics of the two species and their interactions

with the environment. In most systems studied, carabids are represented as a species complex, which makes interpreting interactions between multiple predator species and multiple insect and/or seed prey more complex. Due to their general predatory habits, carabid beetles are more suited to biological control that involves the conservation of existing populations of natural enemies. Conservation may involve habitat modification, use of refugia and/or restricted use of chemicals in order to maintain and protect natural enemy populations (DeBach 1964, Bugg and Pickett 1998).

Many different techniques have been used in order to determine the kind of food that carabid beetles eat. These range from laboratory and field behavioral studies, serological techniques, gut dissections, and morphological analysis. Several literature reviews on carabids and their prey have been done (Thiele 1977, Luff 1987, Allen and Rajotte 1990, Larochelle 1990).

The role of carabids as effective predators of aphids (*Sitobion avenae* Fabricius, *Metopolophium dirhodum* Walker, *Rhopalosiphum padi* L.) has been well documented (Edwards et al. 1979, Edwards and George 1981, Hance 1987, Winder 1990, Bilde and Toft 1999, Kielty et al. 1999). Winder (1990) conducted a study in which he measured the rates at which aphids fell to the ground from the crop canopy and the rates at which they returned to the crop canopy. He manipulated ground predator density (including carabids) with exclusion barriers, and found that aphid climbing rate was highest when predator densities were lowest, suggesting that ground predators reduced the number of aphids that returned to the canopy (Winder 1990). Edwards and George (1981) and Edwards et al. (1979) performed similar experiments where carabid populations were

manipulated and found that aphid populations were inversely correlated with numbers of carabids.

Many studies have also shown carabids to be effective predators of Lepidoptera larvae such as cutworms (*Agrotis ipsilon* Hufnagle, *Euxoa ochrogaster* Guenée) armyworms (*Pseudaletia unipuncta* Haworth), and codling moth (*Cydia pomonella* L.) (Frank 1971, Best and Beegle 1977a, Lund and Turpin 1977b, Brust et al. 1985, Brust et al. 1986, Mack and Backman 1990, Laub and Luna 1992, Clark et al. 1994, Riddick and Mills 1994, Suenaga and Hamamura 1998). For example, Frank (1971) found that several species of carabids would feed on redbacked cutworm (*Euxoa ochorgaster*) eggs, larvae, and pupae both in the laboratory and in the field. Best and Beegle (1977a) found several carabid species that would consume various stages of the black cutworm *Agrotis ipsilon* in the laboratory. Clark et al. (1994) found that armyworm (*Pseudaletia unipuncta*) damage to corn (*Zea mays* L.) plants was significantly greater in plots where predators (including carabids, staphylinids, and spiders) were removed using pitfall traps. In addition, carabids have been studied as effective predators of other insect pests such as the wheat midge(*Sitodiplosis mosellana* Géhin) (Floate et al. 1990) and carrot weevils (*Listronotus oregonensis* LeConte) (Baines et al. 1990). Overall, it seems that carabids will take advantage of any potential pest or prey population and that few carabid species specialize on just one species or group of pests.

Historically, carabids have been classified primarily as carnivores, with plant matter considered as a minor part of their diet, eaten only when animal prey was not available. However, in recent decades, spermophagy in carabids has received more

attention, and many authors have considered their role in the management of some weed species (Johnson and Cameron 1969, Best and Beegle 1977b, Lund and Turpin 1977a, Barney and Pass 1986a, Brandmayr 1990, Jørgensen and Toft 1997, Menalled et al. 2000). For example, Jørgensen and Toft (1997) studied larval development rates of *Harpalus rufipes* (DeGeer), a common carabid species in Danish cereal fields. They compared development rates of larvae raised on common weed seeds to those raised on a diet of several different insect species and found that developmental time for the first and second instar for those fed the mixed insect diet was about twice as long as the developmental time of those fed the weed seed diet (Jørgensen and Toft 1997). Lund and Turpin (1977a) found that *Harpalus pensylvanicus* (DeGeer) readily ate several different species of weed seeds, including Kentucky bluegrass (*Poa pratensis* L.), redroot pigweed (*Amaranthus retroflexus* L.), and common ragweed (*Ambrosia artemisiifolia* L.). The genera *Harpalus* and *Amara* have primarily been classified as being at least partially, if not primarily, phytophagous (Johnson and Cameron 1969, Thiele 1977, Forsythe 1982, Evans 1994).

## Habitat and Microhabitat

Carabid beetles, like many organisms, are sensitive to the environmental conditions of their habitats. They are an extremely diverse group, with species inhabiting riparian, prairie, forest, and agricultural habitats. Adults are very mobile, and can easily move when local environmental conditions become unfavorable. The soil dwelling larval

stage is less mobile with weak chitinization, and is therefore much more sensitive to disturbances and changes in the habitat. Little is known about the larvae of most species, mainly because they live in the soil and are difficult to find in abundance, and must be associated with adults by rearing in the laboratory. Therefore it is difficult to determine how much of a role larvae play in habitat choice, but it is probably very significant.

Several studies have focused on the effects of habitat and microclimate on carabid fauna. Field edges are a type of habitat which are often composed of a diversity of grasses and broadleaf plants including weed species. This may be a more diverse habitat type that is favorable for carabid beetles when compared with a monoculture agricultural field.

Disturbances such as tillage and harvesting practices and chemical applications imposed by agricultural production may result in a habitat that is not favorable for many natural enemies. The lack of plant diversity frequently found in agricultural monocultures results in a subsequent lack of insect diversity that many natural enemies such as carabids depend on for prey (Bugg and Pickett 1998). A weedy field border can provide diversity of both plant and insect species and therefore helps to support a more robust natural enemy population (Shelton and Edwards 1983, Pavuk et al. 1997). Chiverton and Sotherton (1991) compared herbicide treated field edges with non-herbicide treated field edges and found that the non-treated edges supported a greater diversity of prey items and therefore a greater abundance and diversity of carabids than the herbicide treated edges. Field borders can provide a stable overwintering site for ground beetles and other beneficial arthropods, in addition to providing a refuge when the

field is disturbed by agricultural practices such as harvesting or tilling (Hance et al. 1990, Lys and Nentwig 1991, Lys et al. 1994).

It seems clear from the literature that weedy field margins help promote and maintain high population levels of natural enemies like carabid beetles. The argument has been made that weedy field borders act as an overwintering site not only for beneficials, but for pests also (Sheehan 1986, Russell 1989). However, a population of prey species is necessary to support the carabid population. One of the reasons that pest species can be so successful in cultivated fields is that monoculture crop fields are low in diversity. Low plant diversity can reduce a pest's search time for a host plant, and once located provide an unlimited supply of food. By maintaining some weedy borders, or perhaps even more extreme; creating them within large fields, the farmer can restore some of the plant diversity to the field. As a result, as natural enemy populations are conserved the potential for a pest outbreak is reduced.

The idea of maintaining or creating a refuge habitat for natural enemies is persistent in the literature on integrated pest management and biological control. The basic idea is to create or maintain an area either surrounding the crop as a field border or as a strip within the crop which will provide an alternate habitat for natural enemies (Tonhasca and Stinner 1991, Lys and Nentwig 1992, Lys 1994, Lys et al. 1994, Zangger 1994, Zangger et al. 1994). Unfortunately, agricultural intensification often results in the removal of hedges and field boundaries (Lys et al. 1994).

Lys et al. (1994) examined the effects of within-field weed strips in a cereal field. They found that the area with weed strips supported greater numbers and greater species

diversity of carabids when compared with the control area (no weed strips). The amount of available prey seemed to be the limiting factor in this study. There was a high density and diversity of other arthropod species in the weedy strips, which the authors related to increased carabid numbers and diversity (Lys et al. 1994, Zangger et al. 1994). Hance et al. (1990) also compared the abundance and diversity of carabids in a winter barley field with the adjacent weedy border and also found that the border supported greater diversity and abundance of carabids.

In addition to being opportunistic predators, carabid beetles are extremely sensitive to microclimatic factors (Hance et al. 1990, Lövei and Sunderland 1996). Temperature and humidity extremes are not easily tolerated. In a row crop, there is often a large amount of bare, exposed ground between rows of crops. This often results in a very hot and dry ground surface for the beetles. The weedy field edge usually has a dense, more diverse plant canopy which results in a comparatively more humid and cooler microclimate at the ground surface.

Field borders also often have a greater amount of organic material or leaf litter on the ground surface than cultivated fields. Several studies have shown the positive effects of increased organic material on carabid diversity and abundance (House and All 1981, Weiss et al. 1990, Tonhasca and Stinner 1991, Tonhasca 1993, Burton and Burd 1994). The majority of carabid beetles are nocturnal, and the field edge provides a place for the beetles to avoid unfavorable microclimate conditions and predators by hiding in leaf litter and under rocks during the day. Carabids can then move into the field to hunt at night when temperature and humidity conditions in the field are more favorable

## Effects of Tillage on Carabid Beetles

The main differences between conventionally till and no-till systems involve soil structure and the amount of organic matter present (House and Parmalee 1985, House and Brust 1989). In general, the soil in conventional till systems is periodically disturbed by tillage equipment. Different kinds of tillage equipment can vary in the amount of disturbance they cause and may result in variable moisture loss and potential for soil erosion (Young et al. 1994). In addition, organic matter is often reduced in conventional till systems (Young et al. 1994). Most crop residues are buried in the process of tillage and decomposition processes are often accelerated by the increased amount of oxygen introduced by soil mixing (House and All 1981, Stinner et al. 1988).

Long-term no-till systems result in improved soil structure that includes small uniform aggregates, greater infiltration, and increased soil moisture storage capacity and use efficiency (House and Crossley 1987, Stinner et al. 1988). In addition, no-till systems leave crop residues on the soil surface in the field to decompose slowly, resulting in increased soil organic matter (Domitruk et al. 1997). In general, no-till systems tend to support a greater diversity of soil invertebrates.

Several studies have found a clear association between high carabid numbers and diversity in no-till systems when compared to conventional till (House and All 1981, House and Stinner 1983, House and Crossley 1987, Weiss et al. 1990). These authors attribute this trend to availability of prey. Some also hypothesize that increased amount of litter, or crop residues act as a refuge for the beetles, and are therefore associated with

higher numbers of carabids. It has also been found that certain species of carabid beetles may be effective weed seed predators, and since weed seeds are usually in greater abundance in no-till systems, this could also be attractive to maintaining higher populations of some carabid species (Lund and Turpin 1977a, House 1989).

Other studies, however, have found that there is no association between no-till and greater carabid abundance. Barney and Pass (1986b) found that carabid species varied in their response to tillage systems, with some species increasing in no-till, while others clearly increased in conventional till. Their overall finding was that carabids as a group were least abundant and least diverse in no-till. Cárcamo (1995) also captured greater numbers of and greater diversity of carabids in conventional till barley fields than in no-till.

Conventional tillage has a consistent deleterious impact on soil arthropod community composition when compared with no-till systems. Tillage reduces arthropod populations in general because it exposes organisms to less favorable microclimate conditions and makes them susceptible to desiccation, mechanical destruction and disrupts their access to food resources (House and Del Rosario Alzugaray 1989). No-till systems, in contrast, maintain more hospitable environmental and soil conditions with less disruption, which results in less moisture loss, and conserves their available prey resources (House and Crossley 1987). The greater retention of residues on the soil surface in no-till systems also helps minimize humidity and temperature fluctuations (Hammond 1987, Tonhasca and Stinner 1991).

In general, predaceous arthropod densities increase with no-till practices due in part to the presence of plant residues as a refuge, lack of disturbances to the system in general, and generally higher populations of potential prey (House and All 1981, Blumberg and Crossley 1983, Clark et al. 1993). As a result, no-till systems often require a more vigilant integrated pest management monitoring program because both pest and natural enemy populations are often enhanced (House and Del Rosario Alzugaray 1989).

## Effect of Crop Type on Carabid Beetles

The diversity and structure of plants can greatly influence habitat suitability and activity of ground beetles and other beneficial arthropods (Norris and Kogan 2000). Rivard (1966) found that different crop types affected the number of beetles captured in pitfall traps. Greater numbers of carabid beetles were found in cereal crops (winter wheat (*Triticum aestivum* L.)and oats (*Avena sativa* L.)) than in forage crops (clover, *Trifolium sp*. and alfalfa, *Medicago sativa* L.) and pastures. He suggested that differences in microclimatic conditions among crops such as increased humidity and ground cover are what caused the crop type effect found in his study. Cárcamo and Spence, (1994) however, found no crop effect on abundance of one species *Pterostichus melanarius* Illiger. Clark et al. (1997) found that carabid species were more abundant in annual crops (wheat, *Triticum aestivum* L., corn, and soybean, *Glycine max* L.) than in perennial crops (alfalfa). Hance and Gregoire-Wibo (1987) found significant differences in species diversity among crop types in their study. In another study, carabid species abundance

and diversity were significantly different between sugar beet (*Beta vulgaris* L.), winter wheat, and winter barley (*Hordeum vulgare* L.) crops, but the differences were primarily among winter and spring crops (Hance et al. 1990). They suggested that these differences were most likely correlated with timing of tillage, pesticide applications, and differences in ground cover (Hance et al. 1990).

In 1996, strategic planning workshops were held in Montana, Nebraska, and North Dakota to bring together stakeholders to identify agricultural production concerns, including pest management problems and economic issues for dryland wheat production in the Northern Great Plains (Johnson 1999). Many producers expressed interest in the economic and long-term management benefits of alternative non-cereal crops to use in rotation with wheat (Johnson 1999). Along with the benefits that new crops bring, new pest problems can emerge. From the strategic planning workshops, the Sustainable Pest Management (SPM) project was developed. The objectives of the SPM project include investigating the interactions of new crop rotations with both beneficial and pest insects (Johnson 1999). Related to the SPM project, the objective of this study was to examine the effect of tillage and crop type on carabid beetle species activity, diversity, and relative abundance.

# CHAPTER 2

## INTRODUCTION

Carabid beetles, also known as ground beetles, are the third largest family in the order Coleoptera. For the most part, carabid beetles are opportunistic feeders, preying on both live and dead insects, and plant material, particularly seeds. They have been identified as important natural enemies because they prey on a variety of pests including insects and weed seeds. Because of their generalist predatory habits, they are often overlooked regarding their potential role in pest management. However, several studies indicate that increased numbers of carabids and other generalist predators such as spiders can effectively keep pest populations in check (Edwards et al. 1979, Edwards and George 1981, Floate et al. 1990, Lövei and Sunderland 1996).

Carabid beetles are among the most important epigaeic predators in temperate agroecosystems. Several factors drive habitat choice for carabid beetles including presence of prey, plant habitat, and microclimatic conditions such as temperature and humidity. The diversity and structure of plants and their management can greatly influence habitat suitability and activity of ground beetles and other beneficial arthropods (Norris and Kogan 2000). Rivard (1966) found that different crop types affected the number of beetles captured in pitfall traps. Greater numbers of carabid beetles were found in cereal crops (winter wheat and oats) than in forage crops and pastures. He

suggested that differences in microclimatic conditions such as increased humidity and ground cover are what caused the crop type effect found in his study. Cárcamo and Spence, (1994) however, found no crop effect on abundance of one species *Pterostichus melanarius*. Clark et al.'s (1997) studies revealed that carabid species were more abundant in annual crops than in perennial crops. Hance and Gregoire-Wibo (1987) found significant differences in species diversity between crop types in their study. In another study, carabid species abundance and diversity were found to be significantly different among sugar beet, winter wheat, and winter barley, but that the differences were primarily between winter and spring crops (Hance et al. 1990). The authors suggested that these differences were most likely correlated with timing of tillage, pesticide applications, and differences in ground cover (Hance et al. 1990).

Tillage systems can also affect carabid beetle populations. Conventional tillage has a consistent deleterious impact on soil arthropod community composition when compared with no-till systems. Tillage reduces arthropod populations in general because it exposes organisms to unfavorable conditions and increases their susceptibility to desiccation and mechanical destruction and disrupts their access to food resources (House and Del Rosario Alzugaray 1989). No-till systems in contrast, maintain hospitable environmental conditions in the absence of mechanical disruption, which results in less moisture loss, conserves available prey resources, and ameliorates temperature extremes (House and Crossley 1987). This is due in part to the fact that these systems result in soils with higher structural diversity because of greater retention of residues on the soil surface (Tonhasca and Stinner 1991).

# CHAPTER 3

# MATERIALS AND METHODS

This project was part of a larger Sustainable Pest Management (SPM) experiment which was established in 1998 to examine the long-term effects of alternative dryland cropping systems in the Northern Great Plains. The site was located approximately 25 miles northeast of Havre, MT (48.775° N, 110.075° W) at the Mark Peterson Grain and Cattle, Inc. farm. The experiment was a randomized complete block design arranged as split-plot with main plots being conventional till or no-till. There were four replications of the experiment. Subplots were crops within 2, 3, and 4 year crop rotations (see Table 1). Every crop in every rotation was represented each year.

## Management of Experimental Plots

This experiment was established on a 50-acre parcel of land that was in the Conservation Reserve Program from 1988-1997. Glyphosate (Monsanto, St. Louis, MO) herbicide was used to terminate the grass/alfalfa CRP planting in the spring of 1997. The conventional till main plot areas of the experiment were tilled prior to planting in the spring of 1998 (Carlson and Lenssen 1999).

Table 1. Summary of all crops and rotations included in the Sustainable Pest Management Project, Havre 1998 and 1999. Crops sampled for carabid beetles are in bold.

| *Rotation Description* | *1998 Crops* | *1999 Crops* |
|---|---|---|
| Baseline | **Conservation Reserve Program (CRP)** | **Conservation Reserve Program (CRP)** |
| | **Continuous spring wheat** | **Continuous spring wheat** |
| Two year | **Fallow** – Spring Wheat | Fallow – Spring Wheat |
| | Lentil – Spring Wheat | Lentil – Spring Wheat |
| Three year | Fallow – Spring Wheat – Spring Wheat | Fallow – Spring Wheat – Spring Wheat |
| | Fallow – **Yellow Mustard** – Spring Wheat | **Fallow** – **Yellow Mustard** – Spring Wheat |
| | Fallow – Spring Wheat – Safflower | Fallow – Spring Wheat – Safflower |
| | Fallow – **Pea** – Spring Wheat | Fallow – Spring Wheat – **Pea*** |
| | Fallow – Spring Wheat - Chickpea | Fallow – Chickpea – Spring Wheat |
| | | **Pea** – Spring Wheat - **Sunflower** |
| Four year | Fallow – Lentil – Spring Wheat - **Sunflower** | |

* Traps were moved to these pea plots after 1 July 1999, when the pea-spring wheat-sunflower rotation was terminated.

A standard cultivator with overlapping sweeps was used for conservation tillage and the final seedbed was prepared with a Triple-K cultivator. The conventional till fallow plots were cultivated 3 times during each season using sweeps for weed control (see Table 2 for exact dates). All plots were seeded and fertilized with a 12 ft. (3.66 m) wide ConservaPak (ConservaPak Ltd., Indian Head, SK) air seeder. Table 3 summarizes information on crop cultivars, seeding dates, rates, and depths, and fertilizer applications (Carlson and Lenssen 1999).

Table 2. Dates of tillage in 1999 for weed control in conventional till fallow plots. Dates unavailable for 1998.

| Tillage Event | 1999 |
|---|---|
| Tillage 1 | 26 May |
| Tillage 2 | 16 June |
| Tillage 3 | 16 August |

## Carabid Beetle Study

The objective of this project was to examine the effect of tillage and crop type on carabid beetle species activity, diversity, and relative abundance. Six treatments were selected from the rotations described in Table 1: Conservation Reserve Program (CRP), fallow, continuous spring wheat, yellow mustard, pea, and sunflower (see Table 1 for the cropping sequence for these treatments). Conservation Reserve Program plots were

Table 3. Crop cultivars, seeding dates, rates, depths, fertilizer applications, and harvest dates, 1999. Summarized from Carlson and Lenssen 1999.

| Crop | Cultivar | Seeding date | Seeding rate (kg/ha) | Seeding depth (cm) | Urea (kg/ha) | MAP (kg/ha) | Nitrogen (kg/ha) | $P_2O_5$ (kg/ha) | Harvest/ Termination date |
|---|---|---|---|---|---|---|---|---|---|
| spring wheat | McNeal | 20 April | 70.6 | 5.1 | 156.9 | 53.3 | 78.5 | 27.7 | 9 August |
| pea | Alfetta | 20 April | 257.8 | 6.4 | 0 | 53.3 | 5.4 | 27.7 | 2 July/ 29 July |
| yellow mustard | AC Pennant | 20 April | 12.3 | 1.3 | 82.9 | 53.3 | 5.4 | 27.7 | 1 August |
| sunflower | Cenex 803 | 20 April | 5.2 | 3.8 | 104.3 | 53.3 | 53.7 | 27.7 | 2 July |

seeded equally with alfalfa (*Medicago sativa* L.), western wheatgrass (*Pascopyrum smithii* (Rydb.) A. Love), slender wheatgrass (*Elymus trachycaulus* (Link) Gould ex Shinners), and green needlegrass (*Nassella viridula* (Trin.) Barkworth). However, after these plants became established, alfalfa accounted for 95% of the cover in these plots. Individual plots measured 14.63 meters by 30.48 meters. Although crops occurred within different crop rotations (see Table 1), crop type and tillage system were the main factors investigated in this study.

Carabid beetles were sampled using pitfall traps. Traps were constructed using plastic 2-liter soda bottles which had the top of the bottle cut off just above the top of the label so that it was approximately 20 cm tall. The neck of the top half of the bottle was cut away, leaving an opening with a diameter of 4-5 cm. The top half was then inverted into the bottom half to create a funnel. A removable plastic 16 oz. drinking cup was placed inside the soda bottle and insects were directed into this cup by the funnel. About 60 ml of undiluted propylene glycol was poured into the bottom of the cup as a killing agent and preservative. Three pitfall traps were placed in the eastern half of each plot. Traps were placed lengthwise approximately 3.7 m from the eastern edge of the plot, with approximately 7.6 m from the northern and southern edges of the plots and between traps. Traps were placed between crop rows so as to minimize disturbance to the crop.

When samples were collected, the funnel was removed, and the drinking cup with preserved insects was removed. The insects in the cup were then separated from the propylene glycol by filtering them through a square of cotton fabric. The dead insects on the fabric were then placed in sample bags and returned to the lab for identification.

Samples were kept in cold storage (4-5° C) until they could be sorted. Carabid beetles were sorted from the rest of the insects and identified to species using Lindroth's (1961-69) keys. Species names were updated using Bousquet and Larochelle's (1993) catalog (see Appendix A for names that have changed since Lindroth's keys). Voucher specimens were deposited in the Montana Entomology Collection at Montana State University, Bozeman, MT.

Pitfall traps were initially set during the third week of May (14 May 1998, 19 May 1999), approximately 3 to 4 weeks post-planting. Carabid beetles were sampled from May through September in 1998 and May through August in 1999. Actual sampling dates in 1998 were 14-20 May, 9-23 June, 1-8 July, 22-28 July, 19-26 August, and 4-12 September. Actual sampling dates in 1999 were 19-26 May, 15-22 June, 1-7 July, 22-28 July, and 16-24 August. Traps were set on day one and then collected on day seven. The traps were then covered and allowed to "rest" for approximately 14 days before they were set again. The purpose of this rest period was to avoid sampling continuously, minimizing the impact of sampling on carabid beetle populations during the season. Each sampling period lasted approximately seven days, dependent on weather conditions. Trap catches from sampling periods that were greater than seven days were corrected for a seven day period.

On 1 July 1999, the pea – spring wheat – sunflower rotation was terminated due to overpopulation of weeds. After these plots were destroyed, traps were shifted into other pea plots associated with the fallow – spring wheat – pea rotation. There were no

other options for sunflower, therefore no data were collected in sunflower plots after July 1, 1999.

In 1999 only, a HOBO® data logger (Onset Computer Corporation, Pocasset, MA) was placed in each crop type and tillage treatment to measure temperature and relative humidity. We placed these data loggers in the crops to determine if the different crop canopies or tillage practices had a significant effect on temperature and relative humidity at the ground level. The data loggers were mounted on wooden stakes that were pounded into the ground so that the data loggers were approximately 9 cm above the ground.

HOBO data loggers collected data from 1 June – 30 June 1999. A base temperature of 5°C for carabid activity threshold was used (Jones 1979). Hourly temperature data were collected and used to calculate degree hours that were summed for each 24 hour period to determine degree days. Degree days were summed over time to get cumulative degree days. Relative humidity was also collected hourly and averaged over 24 hour periods. Data in both tilled and untilled fallow plots were used as a baseline, and relative humidity values from each crop were plotted as the difference from fallow.

## Statistical Analysis

Analysis of variance with sampling date as the repeated measure was performed for each year. (PROC GLM. SAS Institute, Inc. 1998). In addition, an analysis of variance for each sampling date was performed.

# CHAPTER 4

# RESULTS

A total of 9525 and 9188 carabid beetles were collected in 1998 and 1999, respectively. Forty-five and thirty-eight species were represented for 1998 and 1999 respectively (Table 4). In 1998 the five most abundant species (in decreasing order) were *Harpalus fuscipalpis* Sturm, *Amara obesa* (Say), *Amara thoracica* Hayward, *Harpalus paratus* Casey, and *Microlestes linearis* (LeConte). In 1999 the five most abundant species (in decreasing order) were *Harpalus fuscipalpis*, *Microlestes linearis*, *Harpalus reversus* Casey, *Calosoma lepidum* LeConte, and *Amara littoralis* Mannerheim. Total number of each carabid species is summarized in Table 4.

The mean number of each beetle species collected per trap per seven day sampling period is shown for each crop and tillage type in Figures 1-12. Although carabid species composition was similar between no-till and till treatments for most crops, activity levels between tillage systems for some species differed by tillage system in some cases. For example, *Amara obesa* activity was greater in till compared with no-till treatments in spring wheat, pea, fallow, and yellow mustard in 1998 (Figures 2,3,5, and 6). *Harpalus fuscipalpis* activity was greater in no-till plots in pea in 1998 (Figure 3) and yellow mustard and CRP plots in 1999 (Figures 7 and 12), although its activity was greater in till compared with no-till plots in CRP in 1998 (Figure 1). In 1999, *Microlestes*

Table 4. Total number of specimens collected for each carabid species in Northern Montana crop and tillage treatments, 1998 and 1999.

| Species | 1998 | 1999 |
|---|---|---|
| *Harpalus fuscipalpus* Sturm | 3820 | 4850 |
| *Microlestes linearis* (LeConte) | 425 | 1354 |
| *Amara obesa* (Say) | 901 | 262 |
| *Amara thoracica* Hayward | 807 | 146 |
| *Harpalus paratus* Casey | 759 | 5 |
| *Harpalus reversus* Casey | 301 | 354 |
| *Pasimachus elongatus* LeConte | 359 | 269 |
| *Calosoma lepidum* LeConte | 299 | 322 |
| *Amara littoralis* Mannerheim | 323 | 278 |
| *Bembidion nitidum* (Kirby) | 153 | 132 |
| *Harpalus amputatus* Say | 122 | 141 |
| *Bembidion versicolor* (LeConte) | 130 | 113 |
| *Dyschirius globulosus* (Say) | 113 | 99 |
| *Calosoma obsoletum* Say | 172 | 35 |
| *Piosoma setosum* LeConte | 42 | 154 |
| *Harpalus ventralis* LeConte | 82 | 112 |
| *Agonum placidum* (Say) | 92 | 95 |
| *Poecilus scitulus* LeConte | 56 | 92 |
| *Agonum cupreum* Dejean | 72 | 31 |
| *Bembidion rapidum* (LeConte) | 90 | 11 |
| *Poecilus lucublandus* (Say) | 51 | 44 |
| *Amara quenseli* (Schonherr) | 90 | 4 |
| *Bembidion quadrimaculatum dubitans* (LeConte) | 18 | 56 |
| *Calosoma luxatum* Say | 27 | 47 |
| *Bradycellus congener* (LeConte) | 9 | 56 |
| *Cratacanthus dubius* (Palisot de Beauvois) | 12 | 52 |
| *Harpalus desertus* LeConte | 21 | 29 |
| *Cymindis planipennis* LeConte | 34 | 2 |
| *Amara apricaria* (Paykull) | 30 | 5 |
| *Harpalus compar* LeConte | 31 | 0 |
| *Harpalus opacipennis* (Haldeman) | 9 | 17 |
| *Bembidion obscurellum* (Motschulsky) | 18 | 8 |
| *Cicindela punctulata punctulata* Olivier | 20 | 1 |
| *Cicindela purpurea audubonii* LeConte | 16 | 0 |
| *Poecilus corvus* (LeConte) | 6 | 5 |
| *Chlaenius sericeus sericeus* (Forster) | 2 | 2 |
| *Stenolophus comma* (Fabricius) | 2 | 2 |
| *Calleida caerulea* (Casey) | 3 | 1 |
| *Cymindis borealis* LeConte | 1 | 1 |
| *Lebia solea* Hentz | 1 | 1 |
| *Cicindela limbalis* Klug | 2 | 0 |
| *Anisodactylus sanctaecrucis* (Fabricius) | 1 | 0 |
| *Bembidion nudipenne* Lindroth | 1 | 0 |
| *Harpalus somnulentus* Dejean | 1 | 0 |
| *Lebia atriceps* LeConte | 1 | 0 |
| **TOTAL** | 9525 | 9188 |

Figure 1. Mean number of carabid beetles per trap per sampling period in CRP, tillage systems combined, 1998.

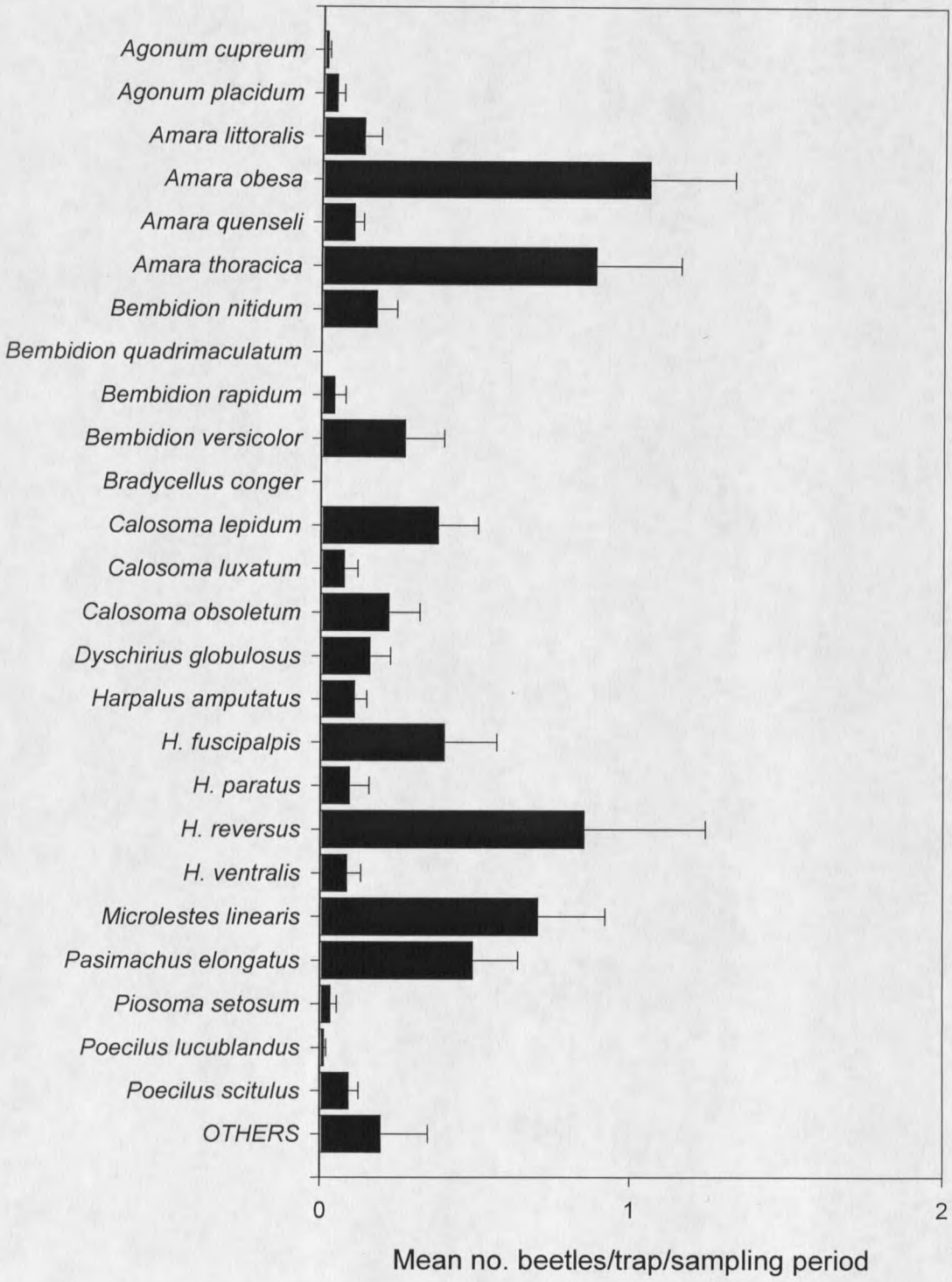


Figure 2. Mean number of carabid beetles per trap per sampling period in till and no-till fallow, 1998.

Figure 3. Mean number of carabid beetles per trap per sampling period in till and no-till pea, 1998.

Figure 4. Mean number of carabid beetles per trap per sampling period in till and no-till sunflower, 1998.

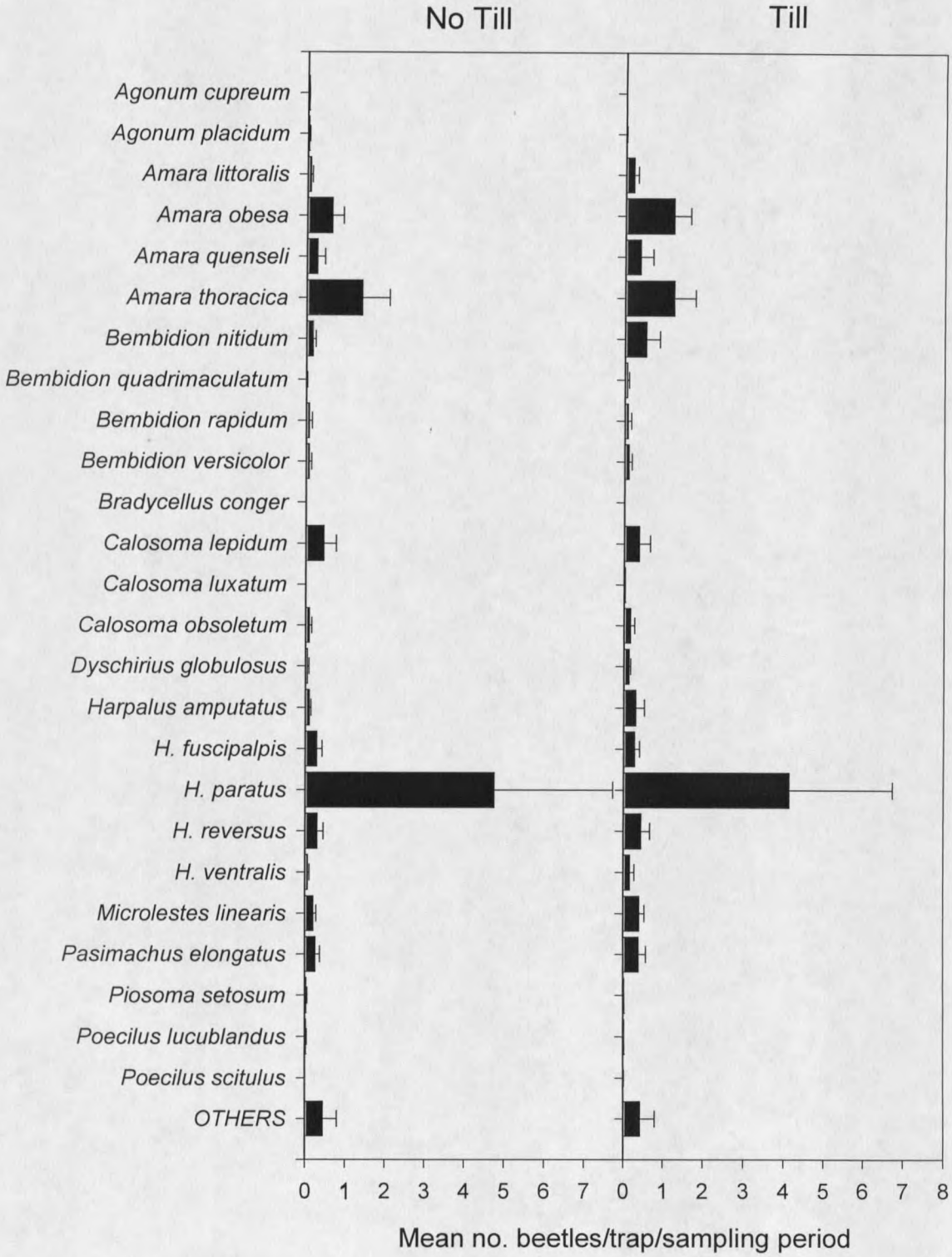


Figure 5. Mean number of carabid beetles per trap per sampling period in till and no-till spring wheat, 1998.

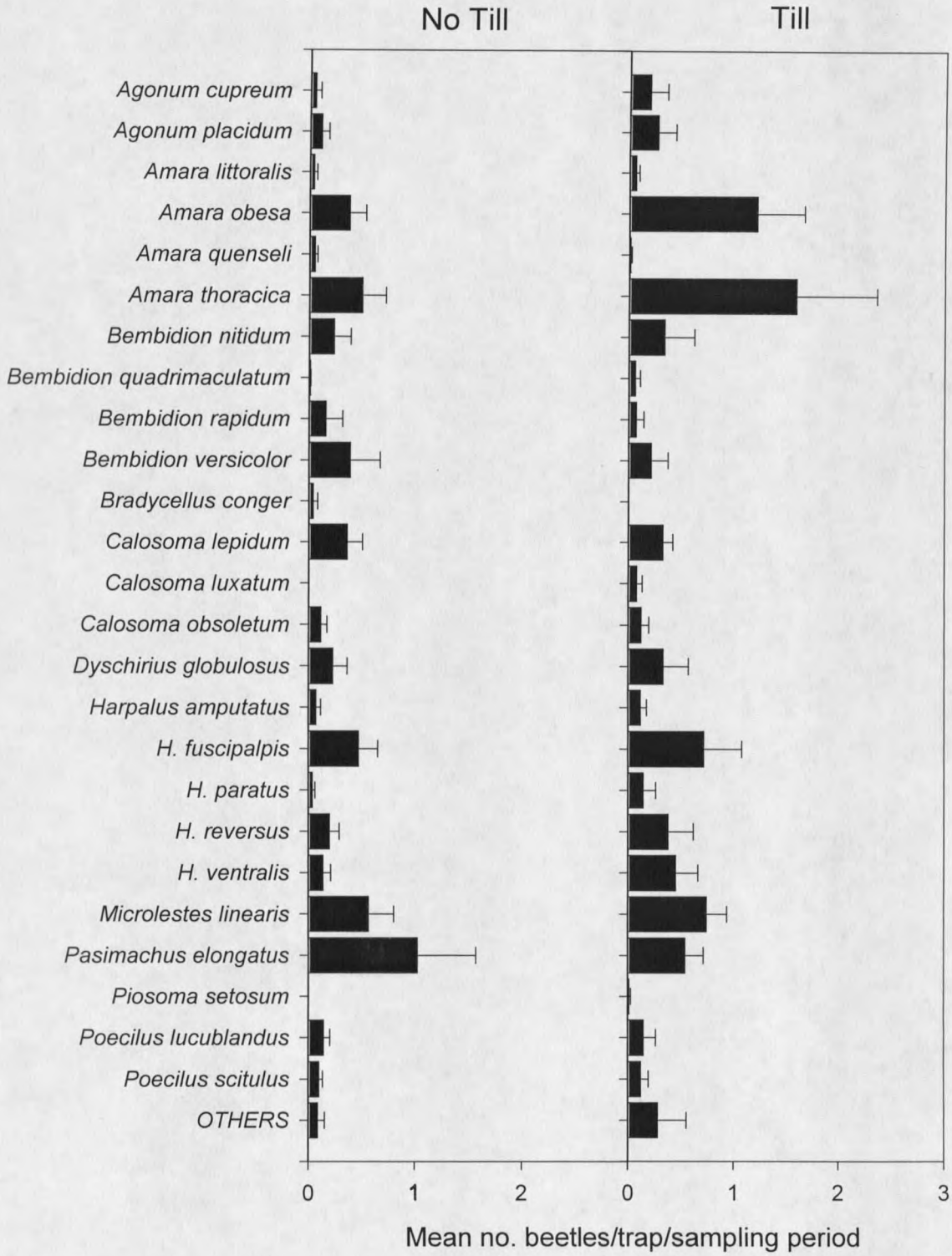


Figure 6. Mean number of carabid beetles per trap per sampling period in till and no-till yellow mustard, 1998.

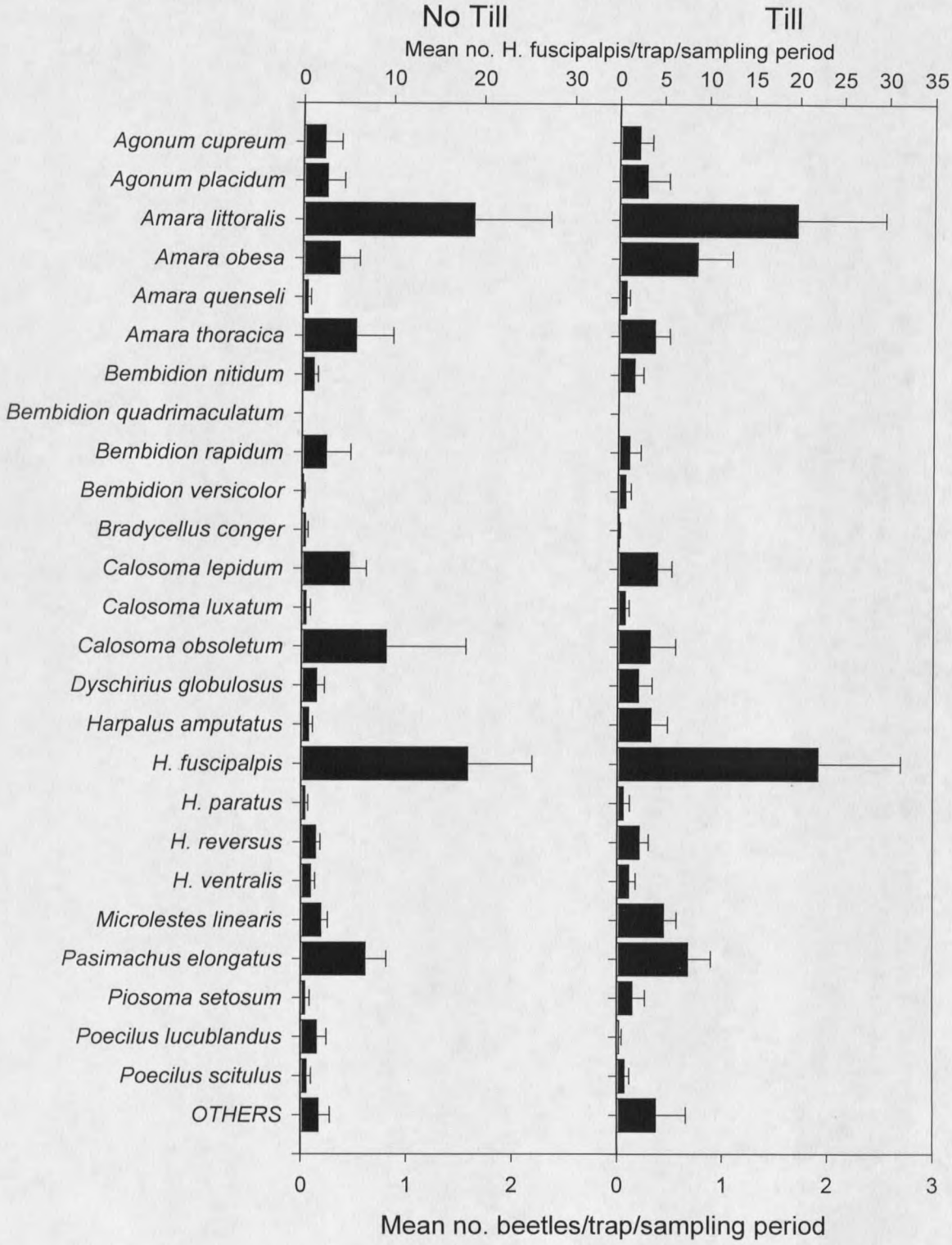


Figure 7. Mean number of carabid beetles per trap per sampling period in CRP, tillage systems combined, 1999.

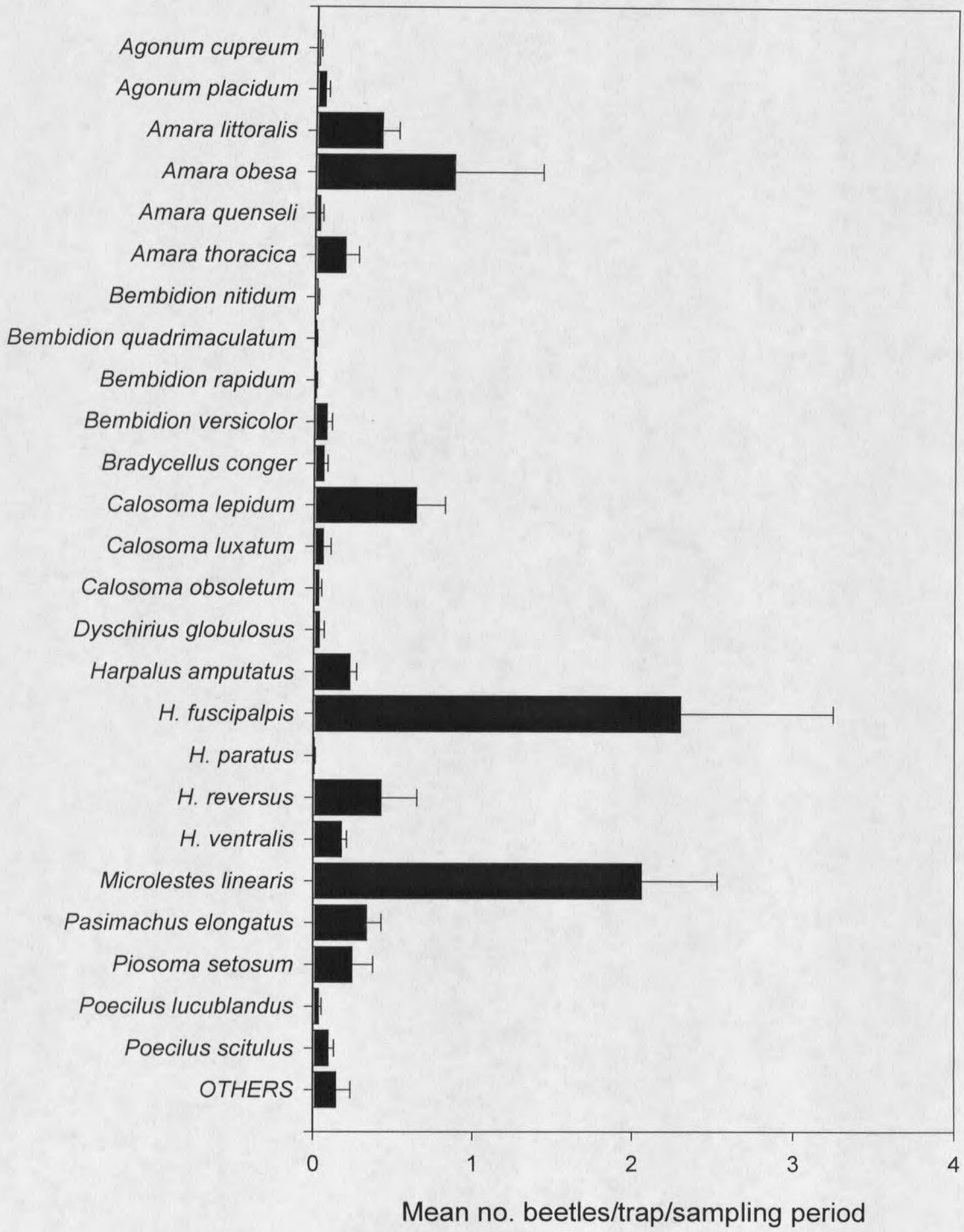


Figure 8. Mean number of carabid beetles per trap per sampling period in till and no-till fallow, 1999.

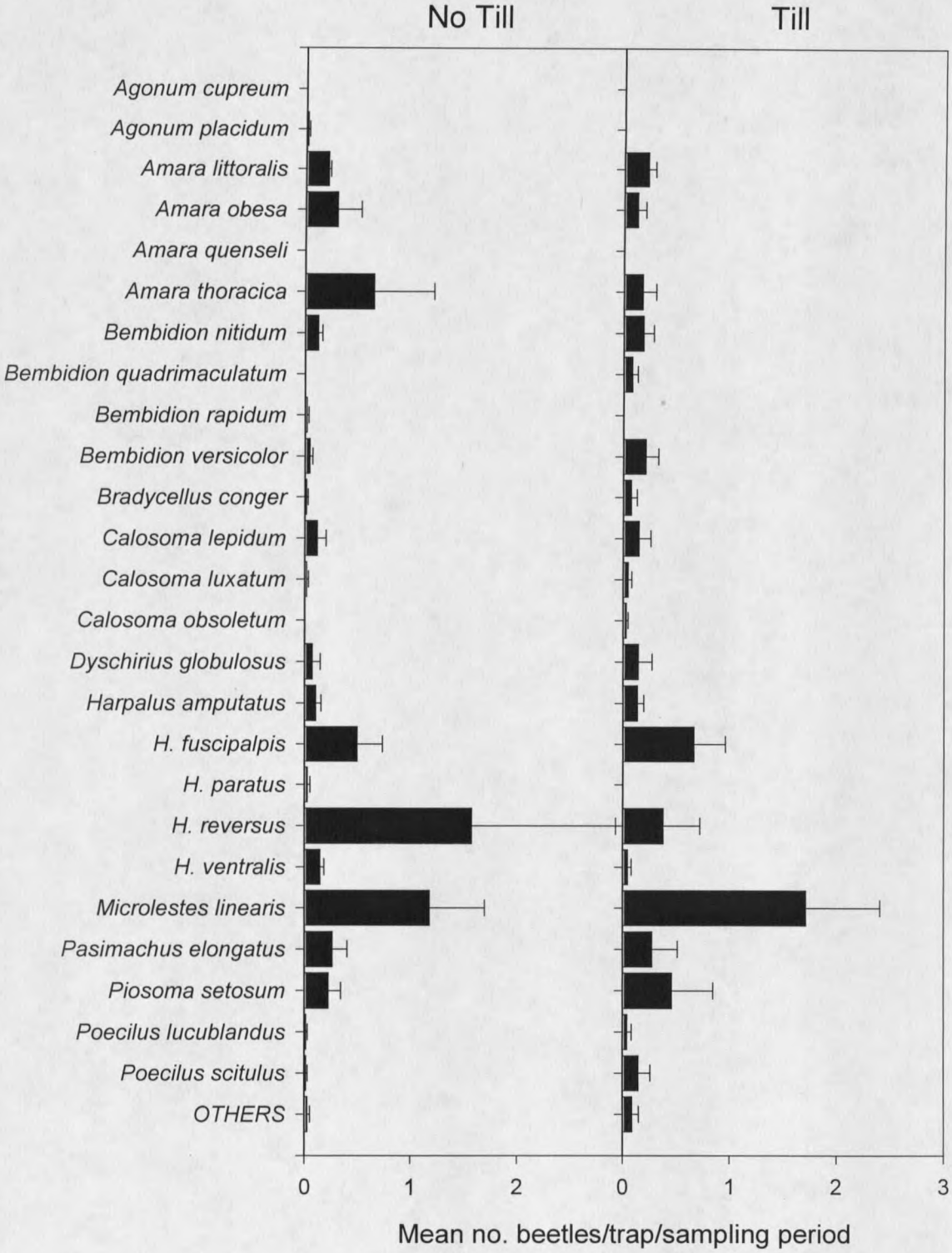


Figure 9. Mean number of carabid beetles per trap per sampling period in till and no-till pea, 1999.

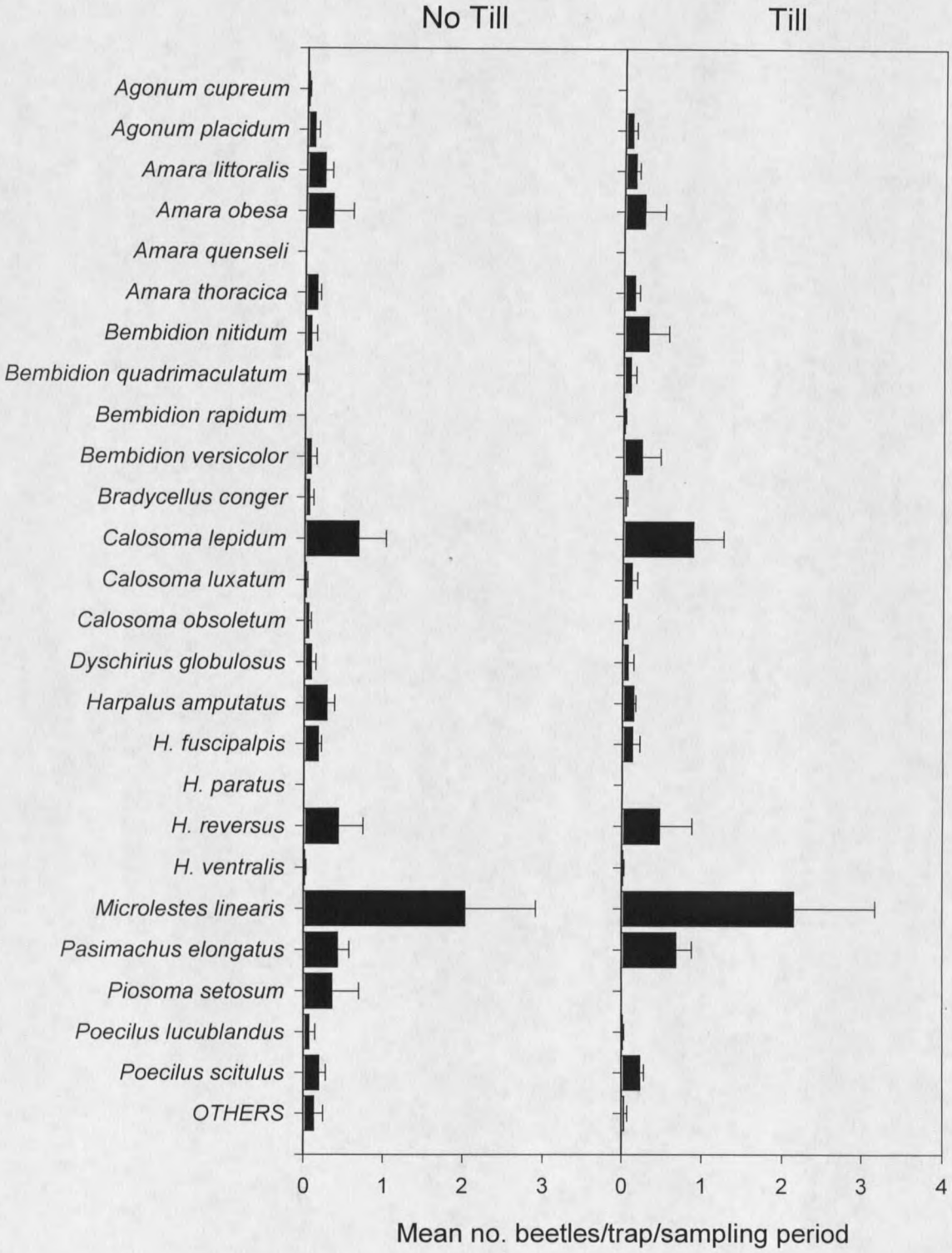


Figure 10. Mean number of carabid beetles per trap per sampling period in till and no-till sunflower, 1999.

Figure 11. Mean number of carabid beetles per trap per sampling period in till and no-till spring wheat, 1999.

Figure 12. Mean number of carabid beetles per trap per sampling period in till and no-till yellow mustard, 1999.

*linearis* activity was greater in the till compared with the no-till treatments in all crops except for pea (Figure 9). The "Others" category combines all species in which less than 40 individuals were collected during both years. These species include: *Cymindis planipennis* LeConte, *Harpalus compar* LeConte, *Amara apricaria* (Paykull), *Harpalus desertus* LeConte, *Cicindela punctulata punctulata* Olivier, *Bembidion obscurellum* (Motschulsky), *Cicindela purpurea audubonii* LeConte, *Harpalus opacipennis* (Haldeman), *Poecilus corvus* (LeConte), *Calleida caerulea* (Casey), *Chlaenius sericeus sericeus* (Forster), *Stenolophus comma* (Fabricius), *Cicindela limbalis* Klug, *Cymindis borealis* LeConte, *Lebia solea* Hentz, *Anisodactylus sanctaecrucis* (Fabricius), *Bembidion nudipenne* Lindroth, *Harpalus somnulentus* Dejean, and *Lebia atriceps* LeConte. Although in many cases carabid species activity was similar for tillage systems within crop types, there were some differences in activity between years. The tillage effect on species activity was not consistent between years or within crops.

The total number of carabid beetles between years was significantly different (F=5.29, P=0.02) (Table 4). Differences in carabid activity and species between years were subject to different rates of crop phenological development, management, and environment. For example, in 1998, the sunflower plots reached maturity, however, in 1999, the entire sunflower-pea-spring wheat rotation was terminated on July 1 due to a high weed population. Altering management practices influenced *Harpalus paratus* and *Amara thoracica* numbers which were found almost exclusively in sunflower plots in late July and August 1998. However, with early termination of this crop in 1999, only five

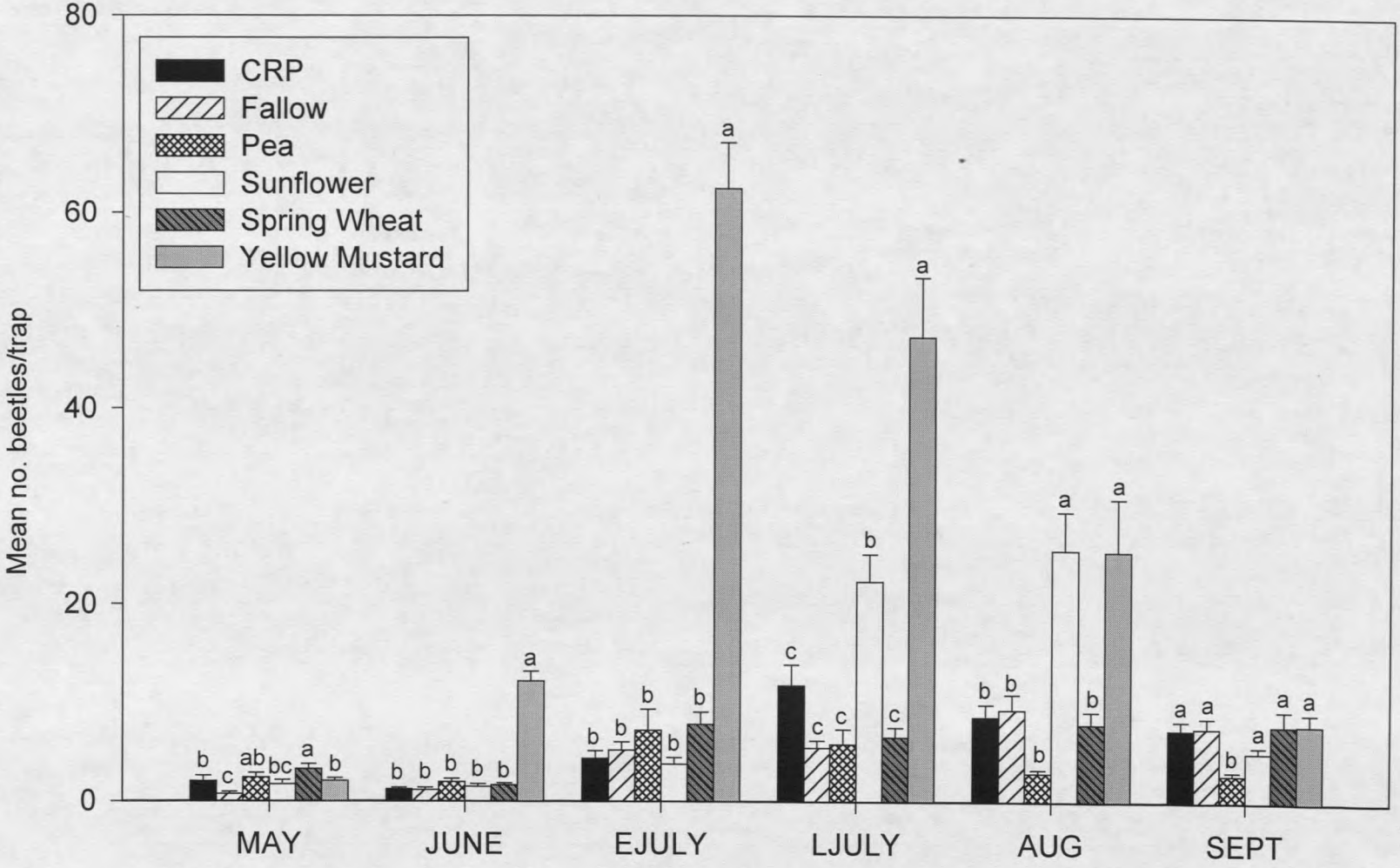
specimens of *Harpalus paratus* (759 in 1998) and 146 specimens of *Amara thoracica* (807 in 1998) were collected.

Carabid Species Overview –1998

In a repeated measures analysis of variance with date as main effect there were significant differences among dates (F=52.86, P<0.01), and there was also a significant date X crop interaction (F=21.56, P<0.01). Tillage was not significant (F=1.55, P=0.18).

Because of the significant date X crop interaction, an analysis of variance by date was conducted and summarized in Figure 13. There were significant differences in total carabid numbers among crops in each of the six sampling periods. In May, crop type was significant (F=3.94, P<0.01). Spring wheat had a significantly greater mean number of carabid beetles per trap (3.29±0.51), than yellow mustard (2.08±0.27), sunflower (1.7±0.46), fallow (0.71±0.24), and CRP (2.04±0.58). Yellow mustard and CRP had significantly greater numbers of carabids than fallow. In June and early July crop was a significant factor (June: F=78.91, P<0.01; early July: F=73.08, P<0.01). For both of these dates, the number of carabids in yellow mustard (12.27±0.96, 62.49±4.66; June and early July, respectively) was significantly greater than the other crops, which were not significantly different from each other. In late July there were significant differences in carabid numbers collected among crops (F=27.11, P <0.01). Yellow mustard (47.33±6.10) and sunflower (22.33±2.81) had significantly different mean numbers of carabids from each other and from other crop treatments. In August crop type was

Figure 13. Mean number of all carabid beetle species per trap. 6 sampling perods are represented, including two periods in July (Early and Late July). Six crops were sampled. Bars with different letters within dates are significantly different ($p < 0.05$). 1998.



significant (F=6.99, P<0.01), with greater numbers of carabids in yellow mustard and sunflower than the rest of the crops. Finally, in September, there were no significant differences among crops. Overall, crop was a significant factor in numbers of carabid beetles collected. In general, yellow mustard had greater numbers of carabid beetles than other crops in the June through August sample dates. Sunflower had greater numbers of carabids than other crops except for yellow mustard in late July, and had greater numbers of carabids than all other crops in August.

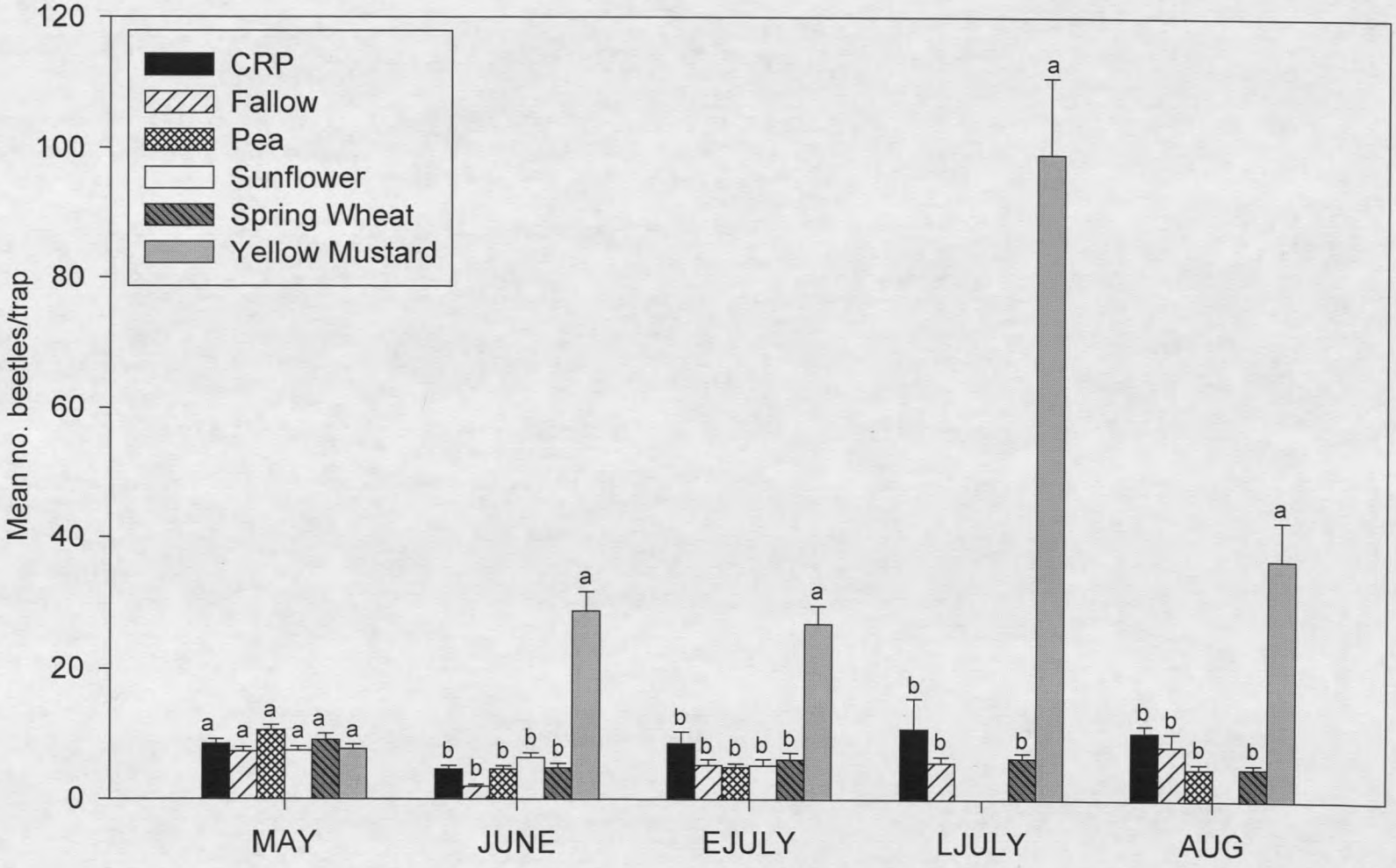
## Carabid Species Overview – 1999

The repeated measures with date as main effect analysis conducted in 1999 found a significant date effect (F=8.86, P<0.01), a significant date X crop interaction (F=16.79, P<0.01), and a significant date X tillage interaction (F=3.64, P <0.01).

The significant date X crop interaction led to an analysis of variance by each sampling date. Figure 14 summarizes the results of this analysis. There were no significant differences among crops in May. June and early July had a significant crop effect (June: F=26.82, P<0.01; early July: F=22.47, P<0.01). The late July sample date had a significant crop type effect (F=82.99, P<0.01), tillage effect (F=7.58, P=0.01), and crop X tillage effect (F=9.58, P<0.01). August had a significant crop effect only (F=12.03, P<0.01).

In the June through August sample dates, yellow mustard (28.80±2.91, 26.88±2.72, 99.08±11.72, 36.75±5.97; June, early July, late July, and August,

Figure 14. Mean number of all carabid beetle species per trap. 6 sampling periods are represented, including two periods in July (Early and Late July). Six crops were sampled. Bars with different letters within dates are significantly different ($p < 0.05$). 1999.



respectively) had significantly greater numbers of carabid beetle activity than the rest of the crops, which were not significantly different from each other. In the date X tillage analysis, numbers of carabid beetles tended to be lower, though not significant, in no-till plots prior to late July when numbers of carabids collected tended to be greater in the no-till plots (Figure 15).

## Degree day accumulation and relative humidity

Degree day accumulation was plotted for crops in both tillage systems in 1999 (Figures 16 and 17). Prior to 9 June 1999 (Julian date 155), degree day accumulation in all crops was similar. After this point, in both till and no-till plots, yellow mustard diverged from the rest of the crops, accumulating degree days below the plant canopy at a slower rate than the rest of the crops. In tilled plots, spring wheat tended to accumulate degree days at a greater rate than other crops (Figure 16). In no-till plots, pea and CRP tended to accumulate degree days at a higher rate than others (Figure 17). Yellow mustard also differed from the rest of the crops in relative humidity (Figures 18 and 19). In both till and no-till plots, yellow mustard had consistently higher relative humidity values than the rest of the crops although the difference was greater and season-long in no-till plots (Figure 19). In the tilled plots there was less difference between yellow mustard and other crops, with relative humidity converging on about 14 June (Julian date 165). Fallow had the lowest relative humidity in both till and no-till, expected since there was no ground cover in these plots.

Figure 15. Mean number of all carabid beetle species per trap, combined over all crop types. 6 sampling dates are represented, including two periods in July (Early and Late July). Bars with different letters within dates are significantly different ($p<0.05$). 1999.

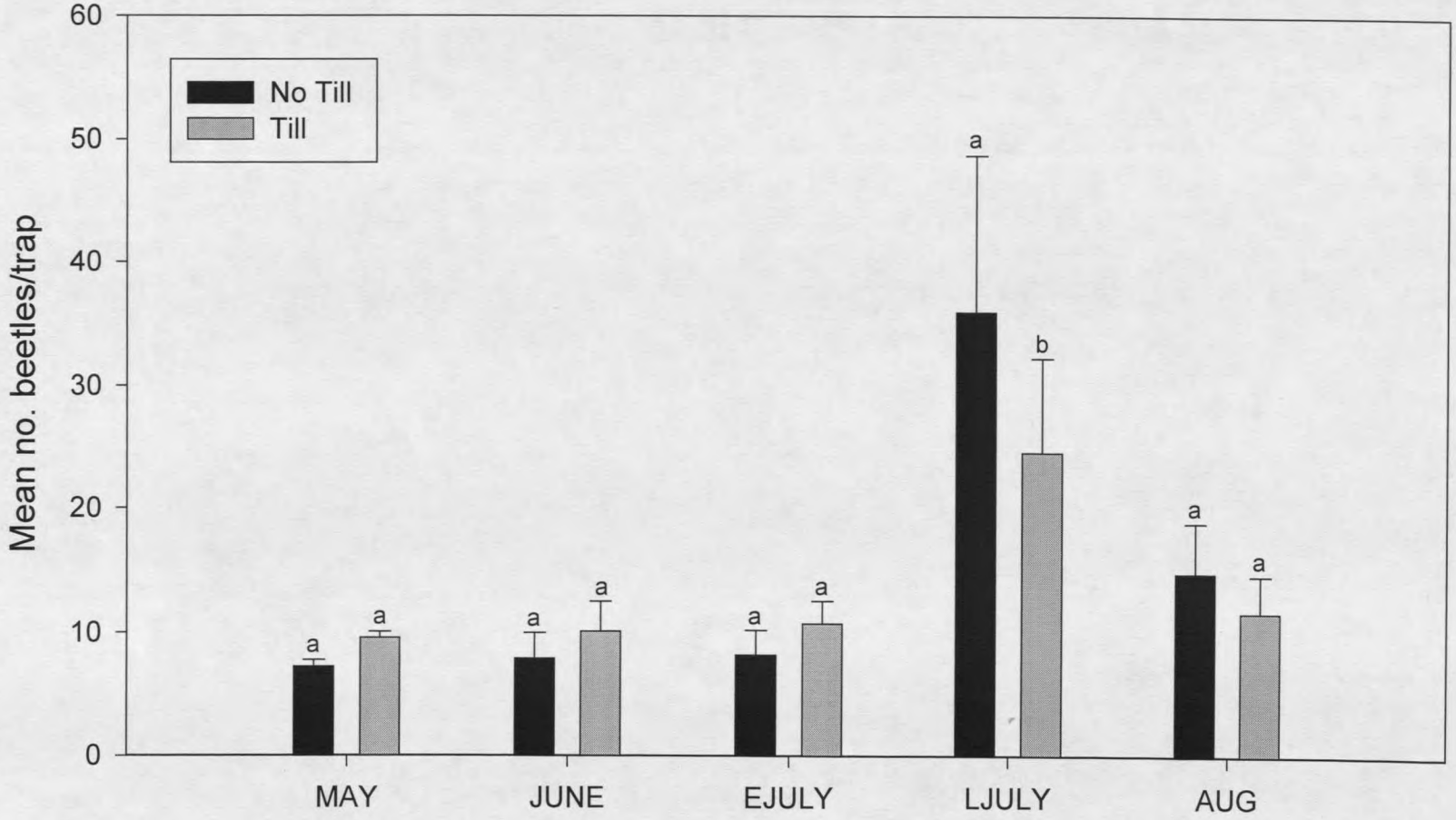


Figure 16. Degree-day unit accumulation in conventional till crops, Havre, MT. 5°C base temperature for ground beetle activity threshold. 1999.

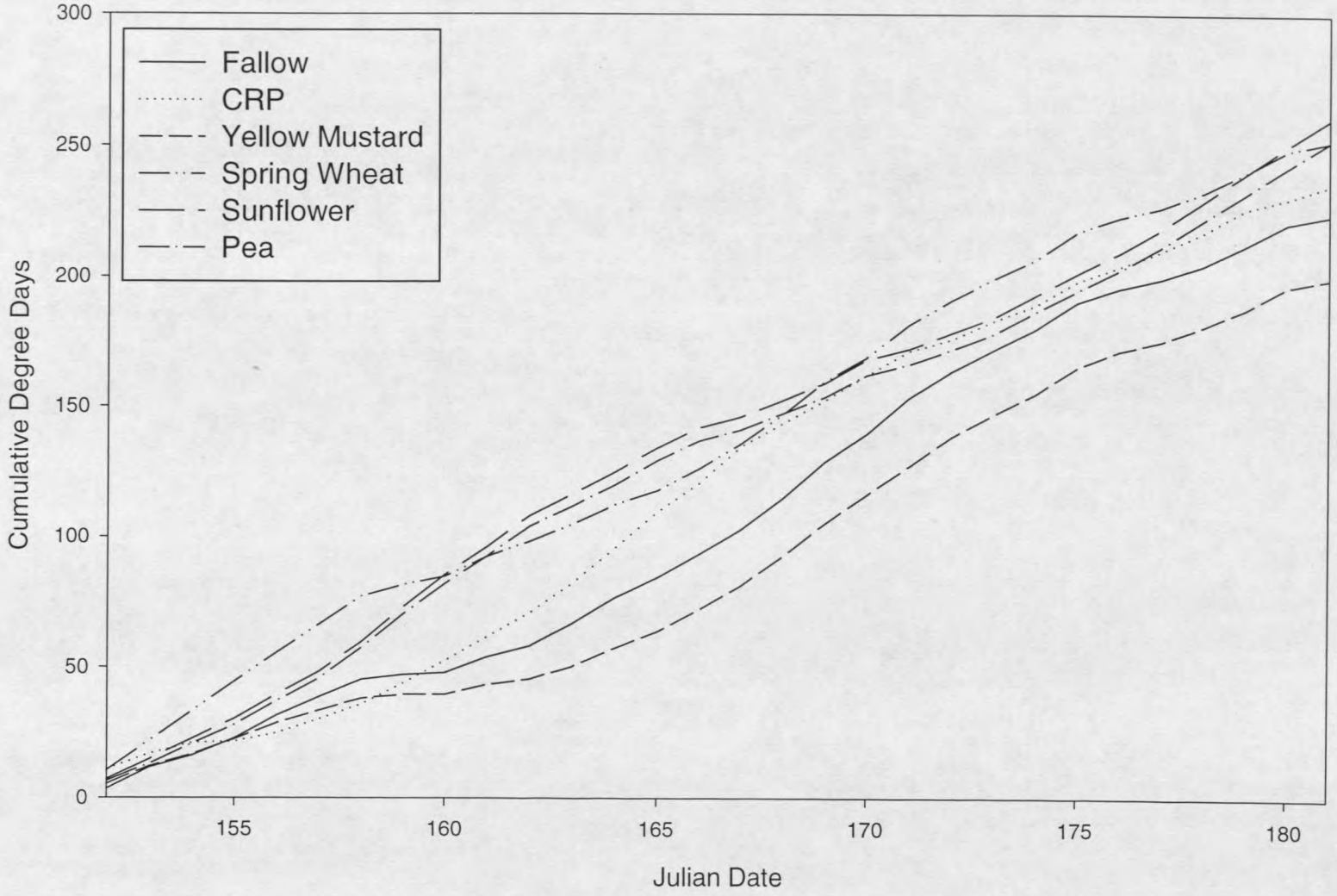


Figure 17. Degree-day unit accumulation in no-till crops, Havre, MT
5°C base temperature for ground beetle activity threshold. 1999.

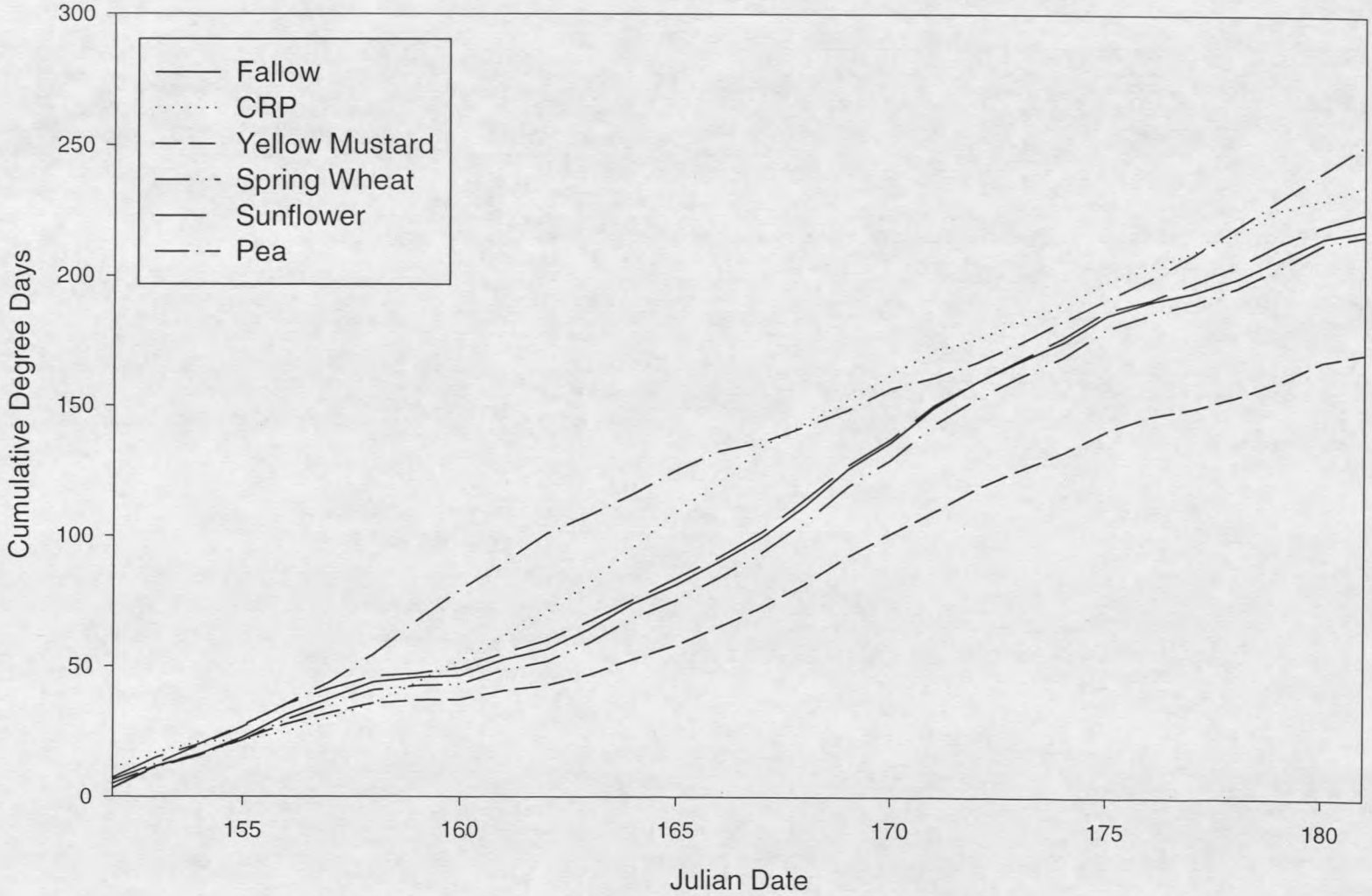


Figure 18. Relative humidity at ground level in conventional till crops, Havre, MT, 1999.

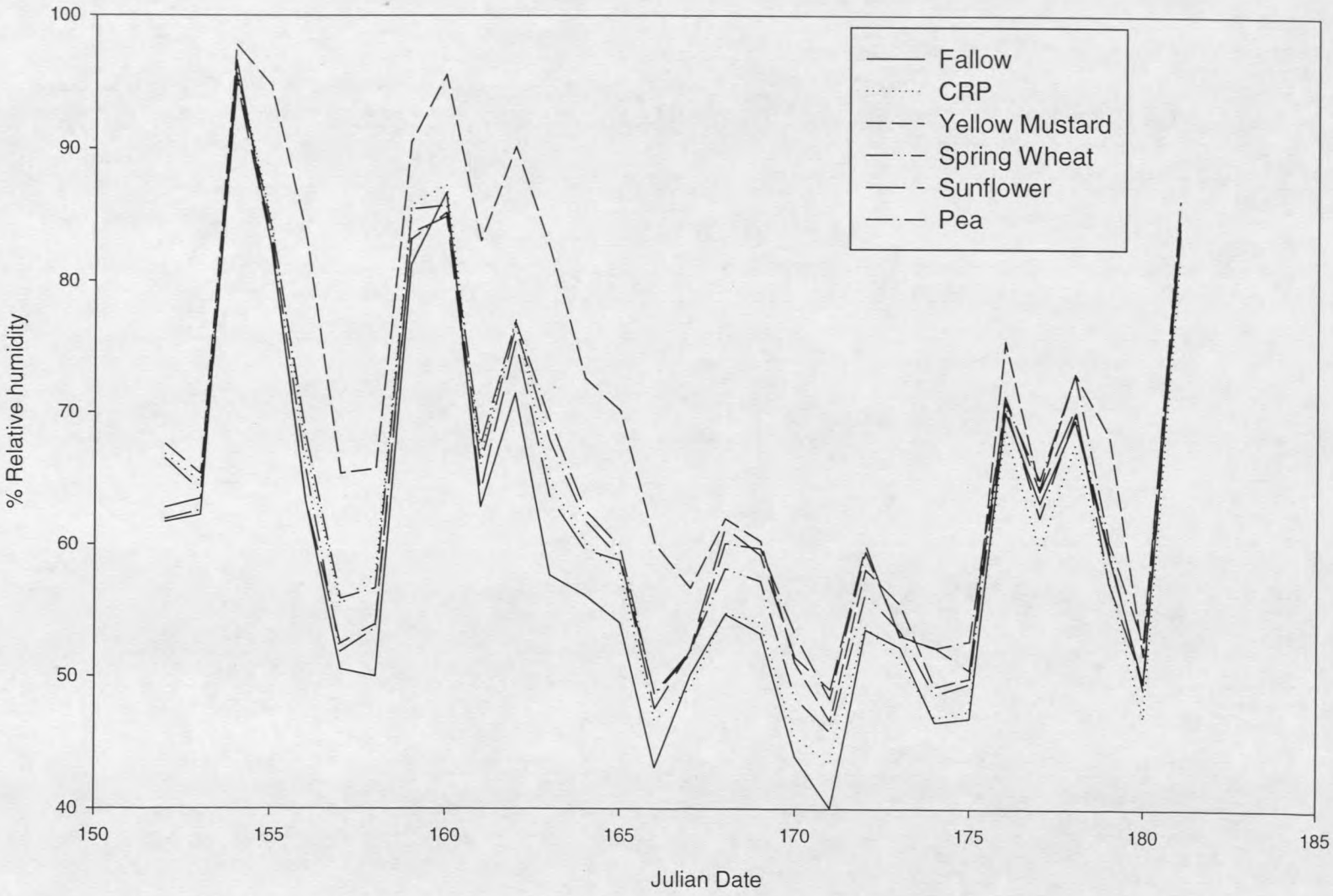
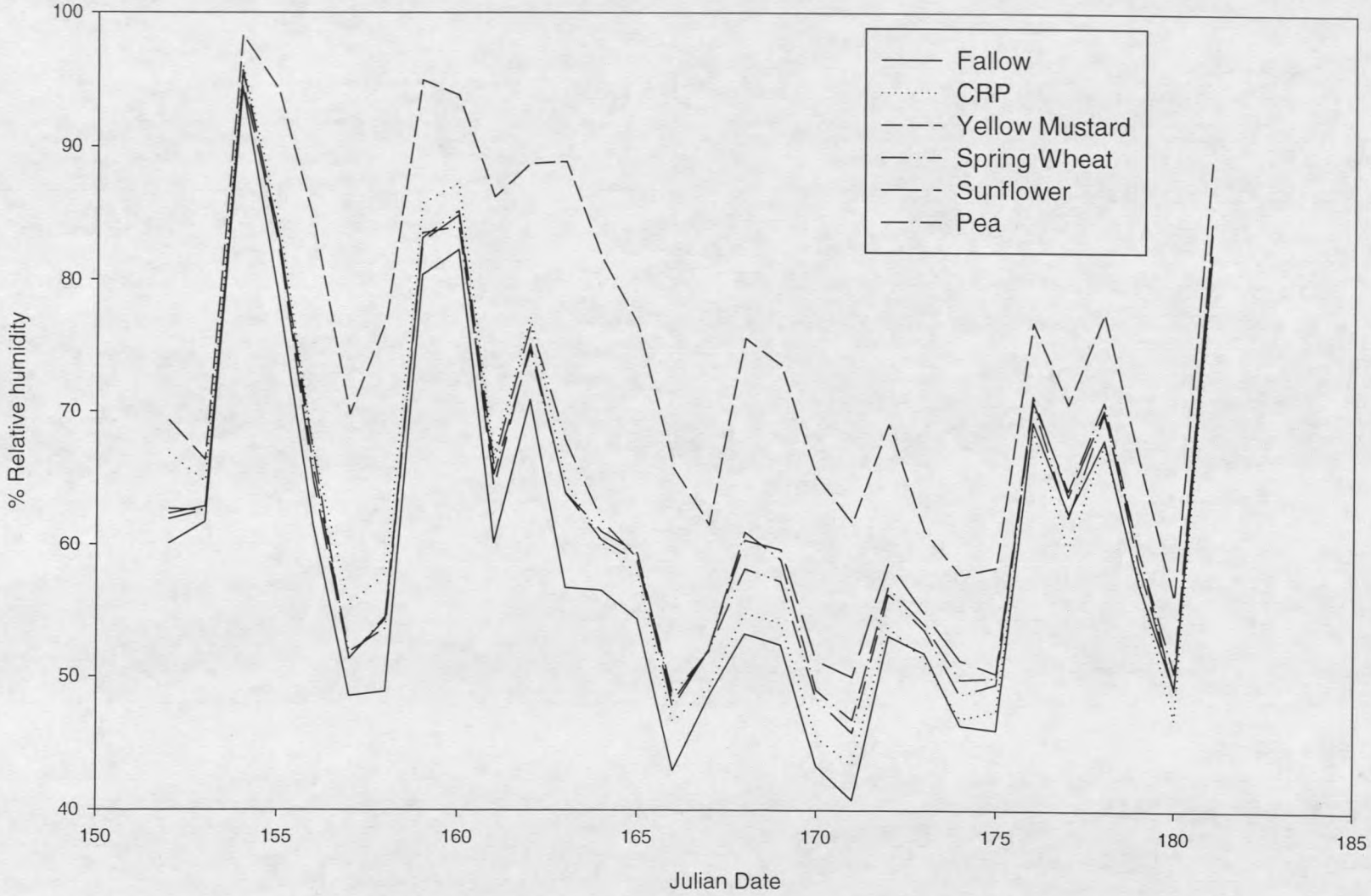


Figure 19. Relative humidity at ground level in no-till crops, Havre, MT, 1999.



## Analyses by Individual Species

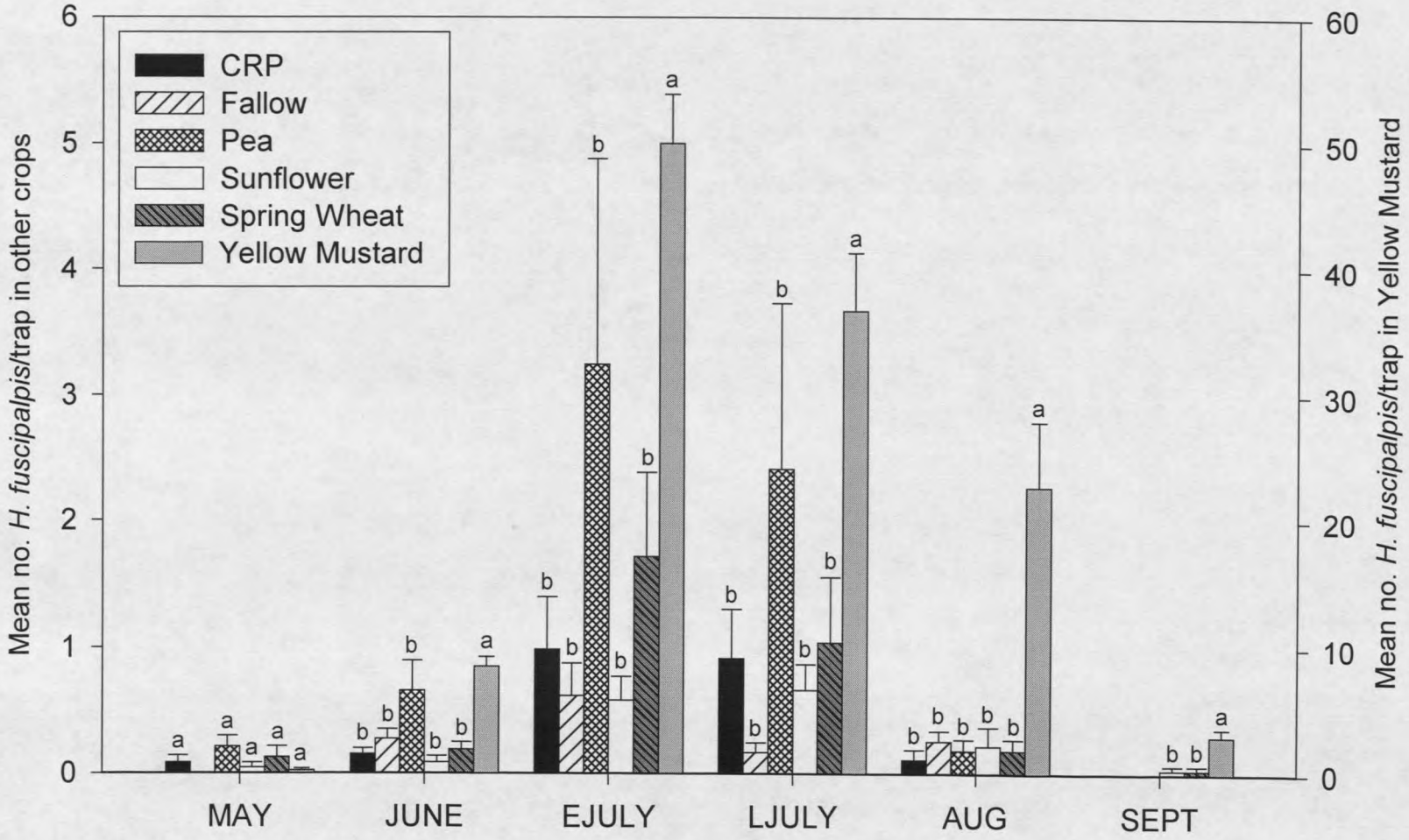
The same analyses that were performed on all carabid species combined (above) were performed on the following individual species: *Harpalus fuscipalpis*, *Amara littoralis*, *Microlestes linearis*, *Amara thoracica*, and *Harpalus paratus*. These species were selected because of their greater activity levels than other species collected in this study.

### *Harpalus fuscipalpis* – 1998

The repeated measures analysis of variance showed a significant date main effect ($F=32.81$, $P<0.01$) and a significant date X crop interaction ($F=23.98$, $P<0.01$) for numbers of *Harpalus fuscipalpis*. There were no significant crop or tillage effects for the May sampling date (Figure 20). The sampling dates June, early July, late July, August, and September all had significant crop type effects (June: $F=91.92$, $P<0.01$; early July: $F=76.47$, $P<0.01$; late July: $F=34.92$, $P<0.01$; August: $F=9.83$, $Pr<0.01$; September: $F=13.53$, $P<0.01$). The June sampling date also had a significant crop X tillage interaction ($F=3.48$, $P=0.01$).

For all of these sampling dates, yellow mustard had significantly greater numbers of carabids than all other crops. The means among the rest of the crops were not significantly different from each other. In June, the crop X tillage interaction was due to significant differences in numbers of *H. fuscipalpis* in yellow mustard till and no-till plots

Figure 20. Mean number of *Harpalus fuscipalpis* per trap in CRP, fallow, pea, sunflower, spring wheat, and yellow mustard for six sampling dates, including two periods in July (EJULY and LJULY, early and late July, respectively). Different letters indicate significant differences ($p<0.05$).
Note: Yellow mustard values are plotted using the right y-axis. All other crop values are represented on the left y-axis. 1998.



only (mean of 10.1 and 7.1, yellow mustard till and no-till, respectively). Other crop and tillage effects were not significantly different.

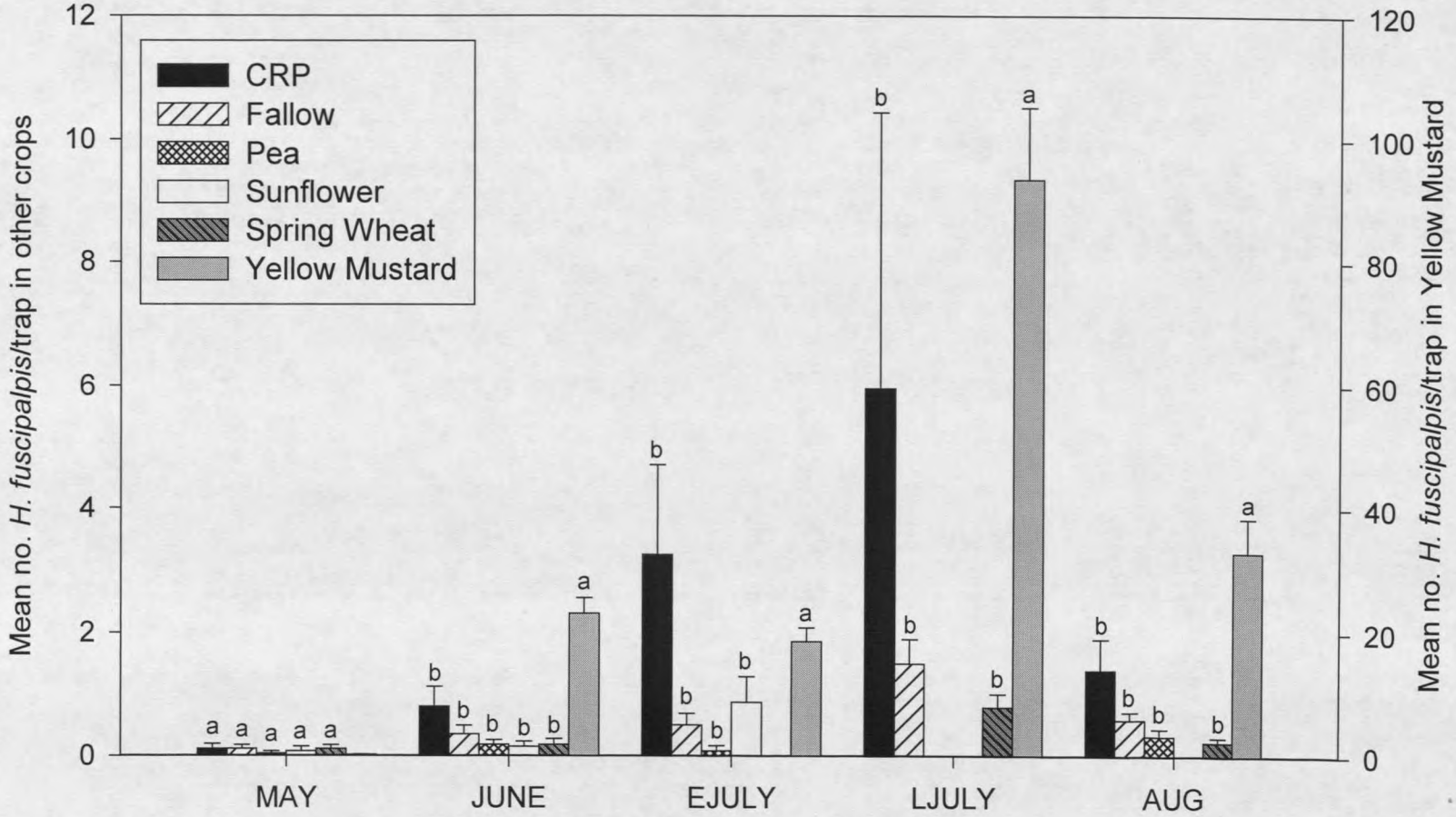
*Harpalus fuscipalpis* – 1999

The repeated measures analysis of variance for 1999 showed a significant date main effect ($F=11.65$, $P<0.01$), a significant date X crop interaction ($F=19.05$, $P<0.01$), and also a significant date X tillage effect ($F=4.64$, $P<0.01$).

The analysis of variance by sampling date had similar results as 1998. There were no significant crop or tillage effects for *H. fuscipalpis* numbers for the May sampling date (Figure 21). The rest of the sampling dates (June through August) had a significant crop effect for *H. fuscipalpis* numbers (June: $F=36.63$, $P<0.01$; early July: $F=26.32$, $P<0.01$; late July: $F=89.97$, $P<0.01$; August: $F=17.01$, $P<0.01$). The late July sampling date also had a significant tillage effect ($F=13.88$, $P<0.01$) and a significant crop X tillage effect ($F=10.07$, $P<0.01$).

As in 1998, yellow mustard was responsible for the significant differences in *H. fuscipalpis* activity among crops. The mean numbers of *H. fuscipalpis* in yellow mustard were much greater than those in the rest of the crops, which were not significantly different from each other. In the late July sampling date, *H. fuscipalpis* numbers in the no-till yellow mustard plots were significantly greater than numbers in the till yellow mustard plots. There were no significant differences among other crop-tillage combinations. The greater activity of *H. fuscipalpis* in no-till yellow mustard compared

Figure 21. Mean number of *Harpalus fuscipalpis* per trap in CRP, fallow, pea, sunflower,spring wheat, and yellow mustard, for six sampling dates, including two periods in July (EJULY and LJULY, early and late July, respectively).
Different letters indicate significant differences ($p<0.05$).
Note: Yellow mustard values are plotted using the right y-axis. All other crop values are represented on the left y-axis. 1999.



with conventional till yellow mustard is a likely cause of the significant date and tillage interaction for all carabid species combined (see Figure 15).

*Amara littoralis* - 1998

The repeated measures analysis of variance had a significant date effect ($F=14.28$, $P<0.01$) and a significant date X crop interaction ($F=10.56$, $P<0.01$). In May, there were no significant differences among crops (Figure 22). In June, there was a significant crop effect ($F=5.71$, $P<0.01$). *Amara littoralis* was present only in yellow mustard and pea, with significantly more individuals in yellow mustard (0.53±0.15, 0.02±0.02; means for yellow mustard and pea, respectively). In both early and late July, crop was significant ($F=36.22$, $P<0.01$; $F=11.83$, $P<0.01$, early and late July, respectively). The mean numbers of *A. littoralis* captured in yellow mustard (3.94±0.52; 4.29±0.95, early and late July, respectively) were significantly greater than the rest of the crops, which were not significantly different from each other. There were no significant differences among crops in August or September.

*Amara littoralis* – 1999

The repeated measures analysis of variance had a significant date X crop interaction only ($F=2.87$, $P<0.01$). In May, there were no significant differences among crop types (Figure 23). In June and early July, there was a significant crop effect ($F=12.68$, $P<0.01$; $F=8.98$, $P<0.01$, June and early July, respectively), with mean number

Figure 22. Mean number of *Amara littoralis* per trap in CRP, fallow, pea, sunflower, spring wheat, and yellow mustard, for six sampling dates, including two periods in July (EJULY and LJULY, early and late July, respectively). Different letters indicate significant differences ($p<0.05$). 1998.

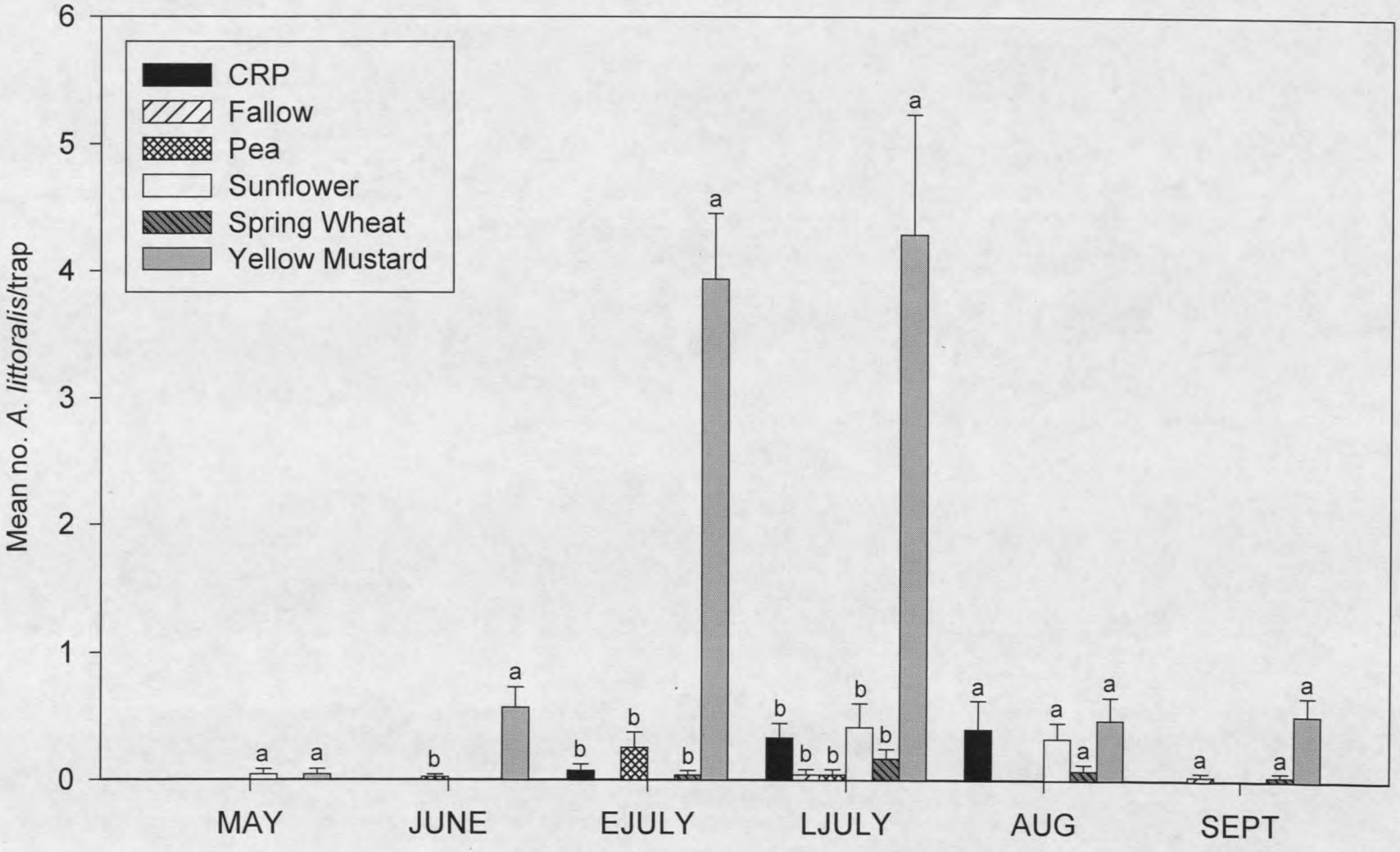
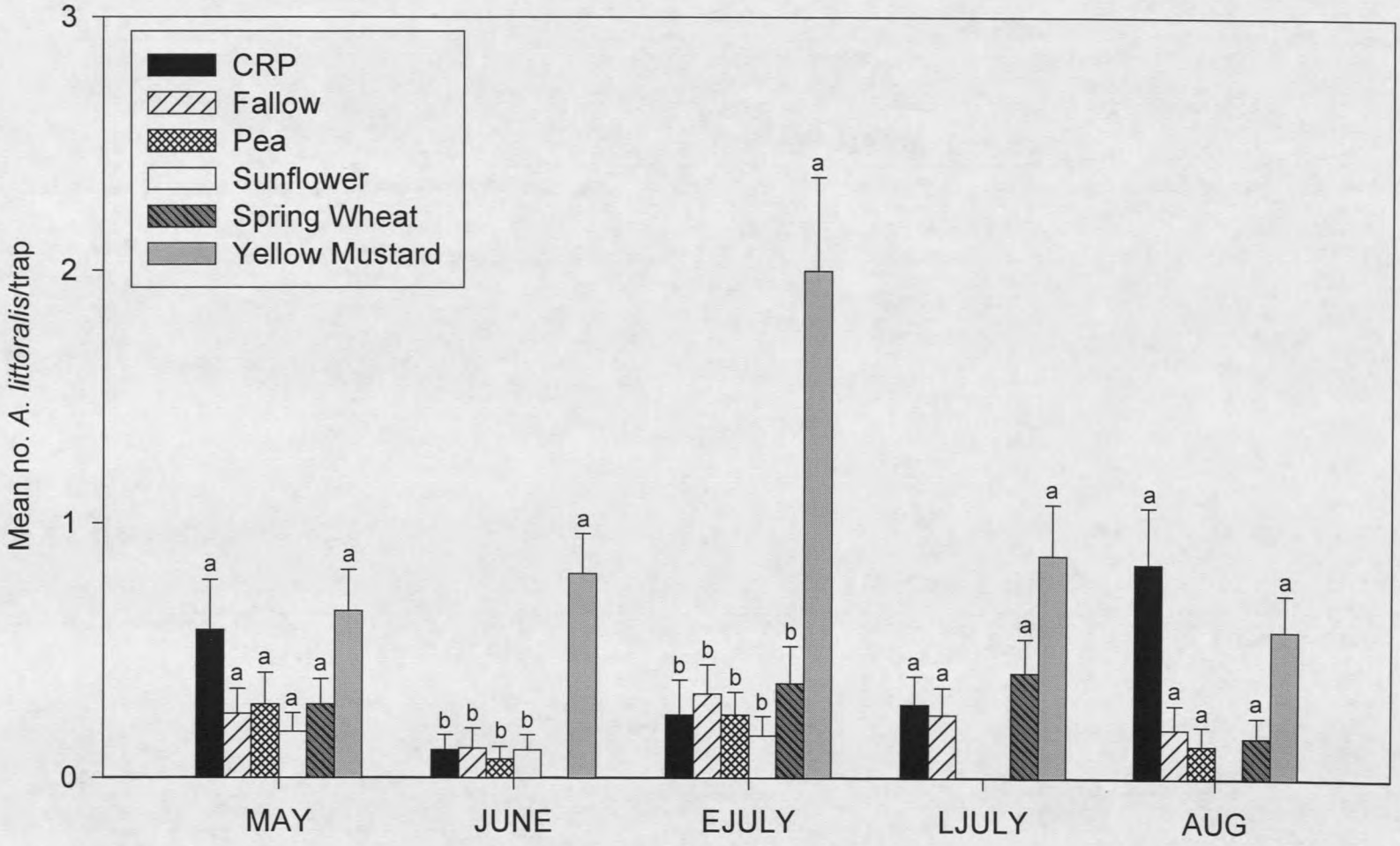


Figure 23. Mean number of *Amara littoralis* per trap in CRP, fallow, pea, sunflower, spring wheat, and yellow mustard, for six sampling dates, including two periods in July (EJULY and LJULY, early and late July, respectively). Different letters indicate significant differences ($p<0.05$). 1999.

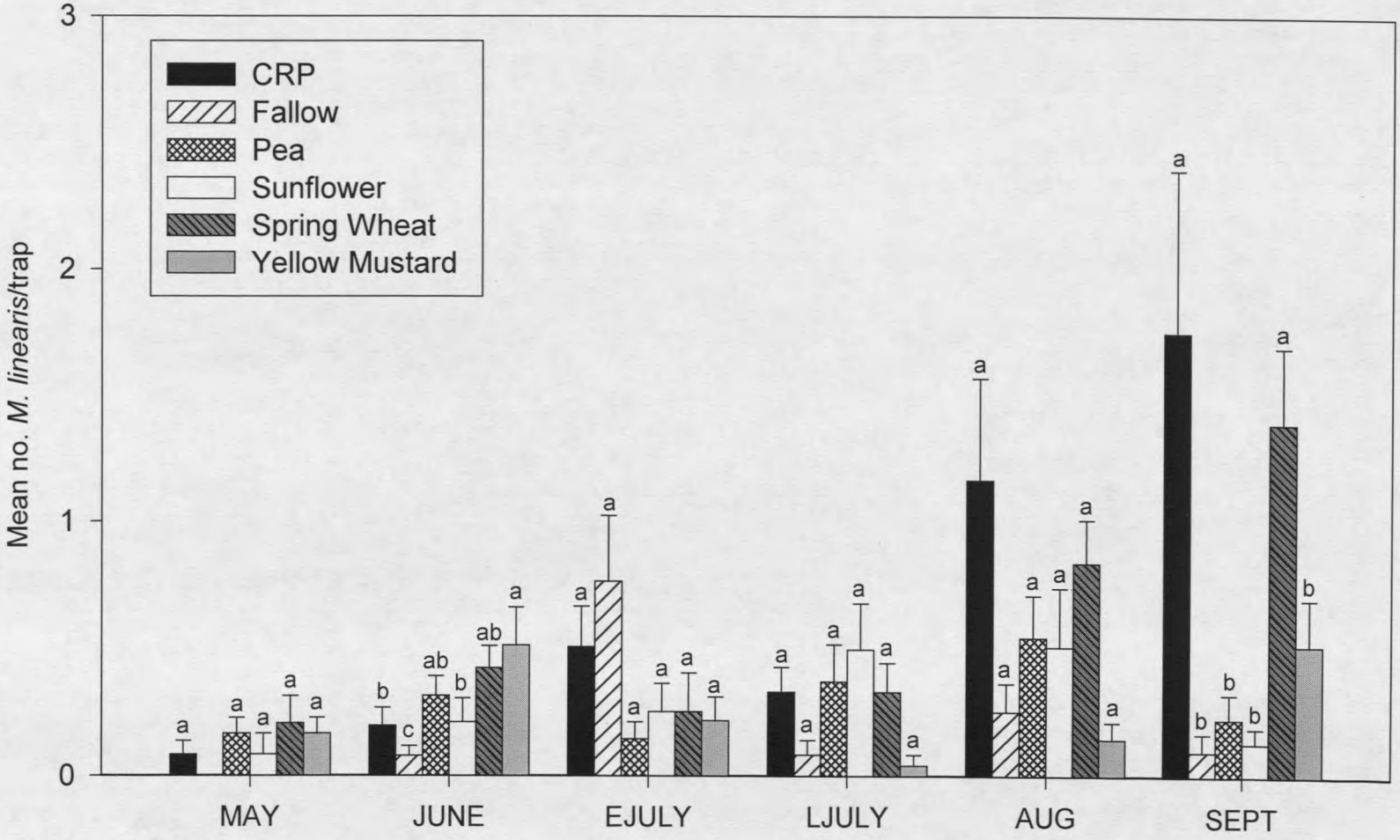


of *A. littoralis* trapped in yellow mustard significantly different than all other crops (0.80±0.15, 2.00±0.37, June and early July, respectively). Other crops on these dates were not significantly different from each other. There were no significant differences among crops in late July or August.

*Microlestes linearis* – 1998

A repeated measures analysis with date as the repeated measure showed a significant date effect (F=7.76, P<0.01), date X crop interaction (F=3.18, P<0.01), and date X tillage interaction (F=2.20, P=0.05) for number of *Microlestes linearis* collected. In May, there were no significant differences among crop types, but there was a significant crop X tillage interaction (F=3.40, P=0.01) (Figure 24). The mean number of *M. linearis* trapped in the till treatment for spring wheat (0.42±0.15), pea (0.25±0.08) and yellow mustard (0.25±0.08) were significantly greater than all other crops and tillage treatments. In June, there was a significant crop effect (F=3.37, P=0.01), and a significant tillage effect (F=6.61, P=0.01). Yellow mustard had a significantly greater mean number of *M. linearis* collected than CRP, sunflower, and fallow. CRP and sunflower were not significantly different than each other, and fallow had significantly less *M. linearis* activity than all other crops. In June, the till treatment had significantly greater *M. linearis* activity than the no-till treatment (0.37±0.04). In early July, late July, and August, there were no significant differences among crops. Finally, in September, there was a significant crop effect (F=9.53, P<0.01) and a signficant crop X tillage interaction (F=3.73, P<0.01). CRP (1.75±0.64) and spring wheat (1.39±0.29) had

Figure 24. Mean number of *Microlestes linearis* per trap in CRP, fallow, pea, sunflower, spring wheat, and yellow mustard for six sampling dates, including two periods in July (EJULY and LJULY, early and late July, respectively). Different letters indicate significant differences ($p<0.05$). 1998.

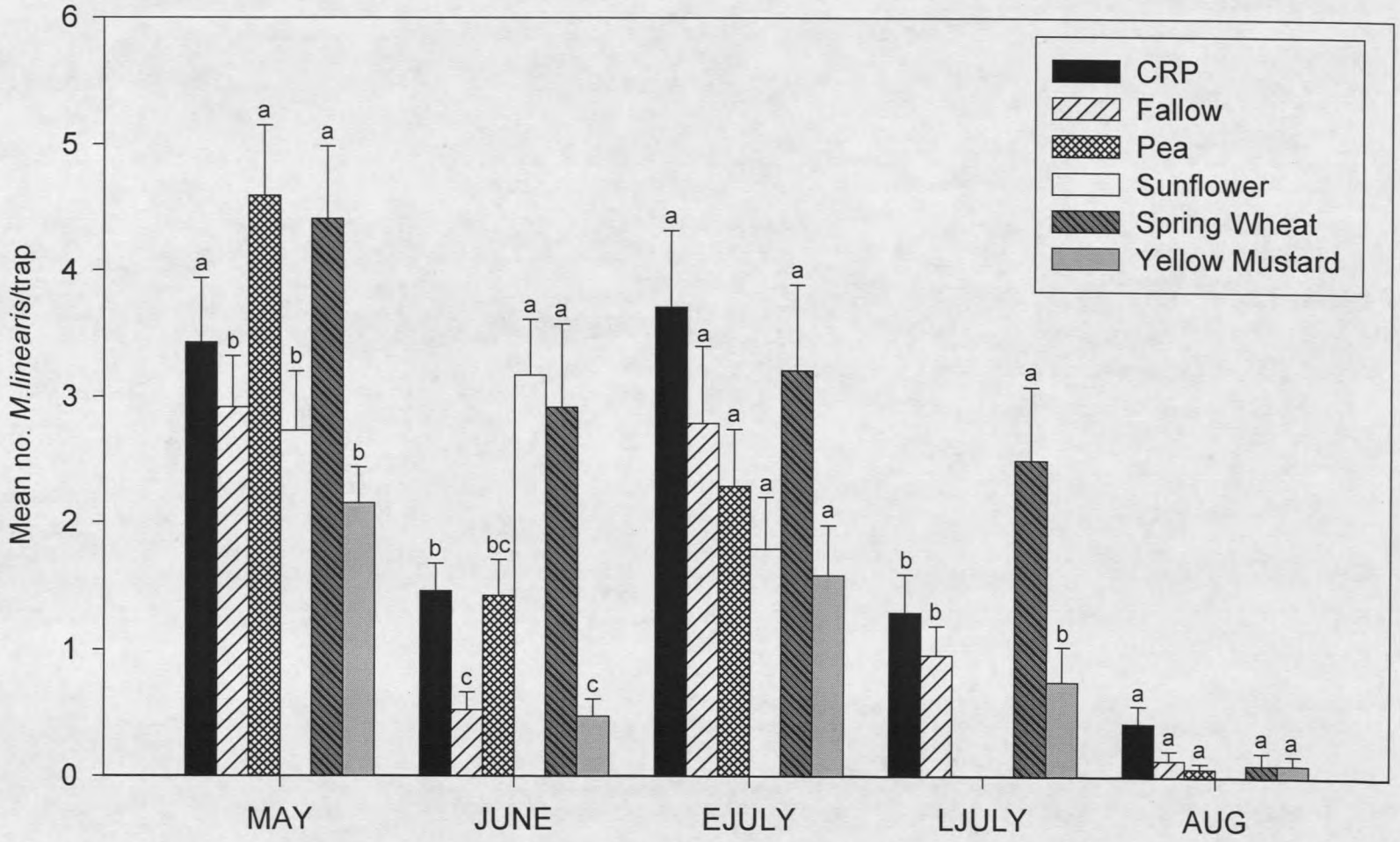


significantly greater numbers of *M. linearis* collected than all other crops, which were not significantly different from each other. The crop X tillage effect was a result of greater *M. linearis* activity captured in no-till CRP (2.72±1.36) which was significantly different than all other crop-tillage treatments.

*Microlestes linearis* – 1999

In general, activity was greater in 1999 than in 1998. A repeated measures analysis of variance with date as the repeated measure showed a significant date effect ($F=16.51$, $P<0.01$) and a significant date X tillage interaction ($F=3.78$, $P<0.01$). In May, there was a significant crop effect ($F=4.07$, $P<0.01$) and a significant tillage effect ($F=11.87$, $P<0.01$) (Figure 25). Mean numbers of *M. linearis* trapped in May were not significantly different in CRP, pea, and spring wheat plots, but they were significantly greater than the activity in fallow, sunflower, and yellow mustard, which were not significantly different from each other. The mean for the till treatment (4.04±0.28) was significantly greater than the no-till treatment (2.69±0.28). In June, there was a significant crop effect ($F=6.93$, $P<0.01$) and a significant tillage effect ($F=5.59$, $P=0.02$). Numbers of *M. linearis* collected in sunflower and spring wheat were not significantly different from each other, but were significantly greater than activity in all other crops. Activity in CRP (1.46±0.22) was significantly greater than activity in fallow (0.53±0.15) and yellow mustard (0.47±0.14). The mean number of *M. linearis* collected in the till treatment (2.02±0.29) was significantly greater than the number collected in the no-till treatment (1.28±0.24). In early July, there were no significant differences among crops.

Figure 25. Mean number of *Microlestes linearis* per trap in CRP, fallow, pea, sunflower, spring wheat, and yellow mustard, for six sampling dates, including two periods in July (EJULY and LJULY, early and late July, respectively). Different letters indicate significant differences ($p<0.05$). 1999.

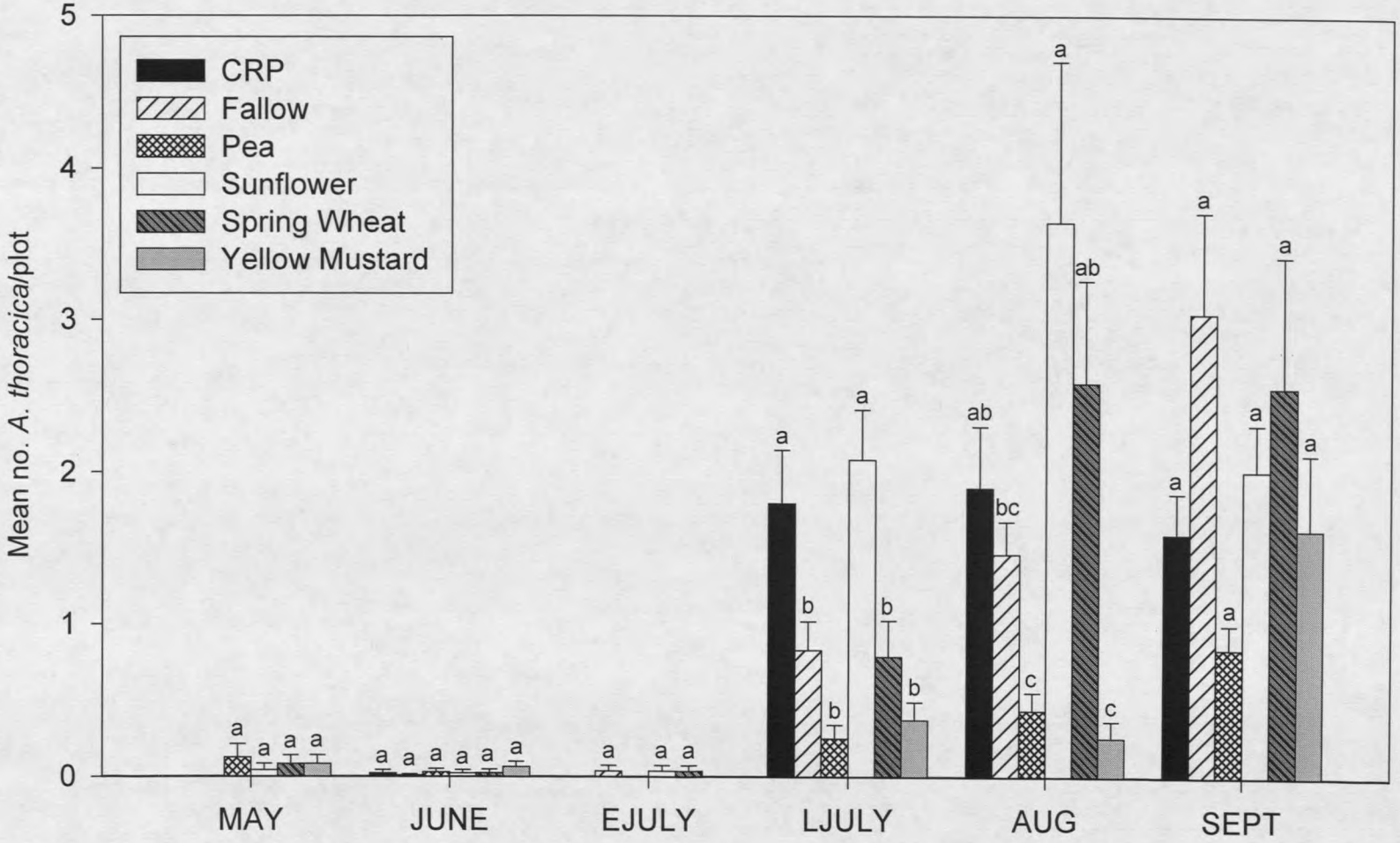


In late July, there was a significant crop effect (F=2.75, P=0.05) and a significant tillage effect (F=14.16, P<0.01). The mean number of *M. linearis* captured in spring wheat was significantly greater than all other crops, which were not significantly different than each other. The mean number of *M. linearis* collected in the till treatment (2.15±0.32) was significantly greater than in the no-till treatment (0.67±0.32). In August, there were no significant differences among crops.

*Amara thoracica* –1998

Repeated measures analysis of variance with date as repeated measure showed a significant date effect (F=24.44, P<0.01) and a significant date X crop interaction (F=2.01,P<0.01). There were no significant differences among crops in May, June, or early July (Figure 26). In late July, there was a significant crop effect (F=6.89, P<0.01). Mean numbers of *A. thoracica* collected in CRP (1.79±0.36) and sunflower (2.08±0.33) were not significantly different from each other, but were significantly different than the rest of the crops. In August there was a significant crop effect (F=3.30, P=0.01). The mean number of *A. thoracica* collected in sunflower was significantly different than the fallow, pea, and yellow mustard. CRP and spring wheat had significantly greater *A. thoracica* activity than pea and yellow mustard. There were no significant differences among crops in September.

Figure 26. Mean number of *Amara thoracica* per trap in CRP, fallow, pea, sunflower, spring wheat, and yellow mustard, for six sampling dates, including two periods in July (EJULY and LJULY, early and late July, respectively). Different letters indicate significant differences ($p<0.05$). 1998.



*Amara thoracica* –1999

Generally, there was more A. thoracica activity in 1998 than 1999. A repeated measures analysis of variance showed a significant date effect (F=6.64, P<0.01) and a significant date X crop interaction (F=3.21, P<0.01). The means of *A. thoracica* captured among crops in May, June, early July, or late July were not significantly different (Figure 27). In August, there was a significant crop effect (F=4.24, P<0.01). Numbers of *A. thoracica* captured in fallow plots (1.78±0.59) were significantly greater than all other crops, which were not significantly different than each other.

*Harpalus paratus* – 1998

The repeated measures analysis showed that there was a significant date effect (F=22.56, P<0.01) and a significant date X crop interaction (F=18.01, P<0.01). In May and June, no specimens of *Harpalus paratus* were collected (Figure 28). In early July, there was a significant crop effect for this date (3.00, P<0.01) and a significant crop X tillage effect (F=3.00, P=0.02). In early July, a total of two individuals were collected, both in sunflower plots. In late July and August there was a significant crop effect (F=32.29, P<0.01; F=18.90, P<0.01, late July and August, respectively). The greatest number of *H. paratus* were collected in sunflower plots (12.20±2.22; 14.00±2.95, means for late July and August respectively). The rest of the crops were not significantly different than each other. In September, there were no significant differences in number of *H. paratus* collected among crop types.

Figure 27. Mean number of *Amara thoracica* per trap in CRP, fallow, pea, sunflower, spring wheat, and yellow mustard, for six sampling dates, including two periods in July (EJULY and LJULY, early and late July, respectively). Different letters indicate significant differences ($p<0.05$). 1999.

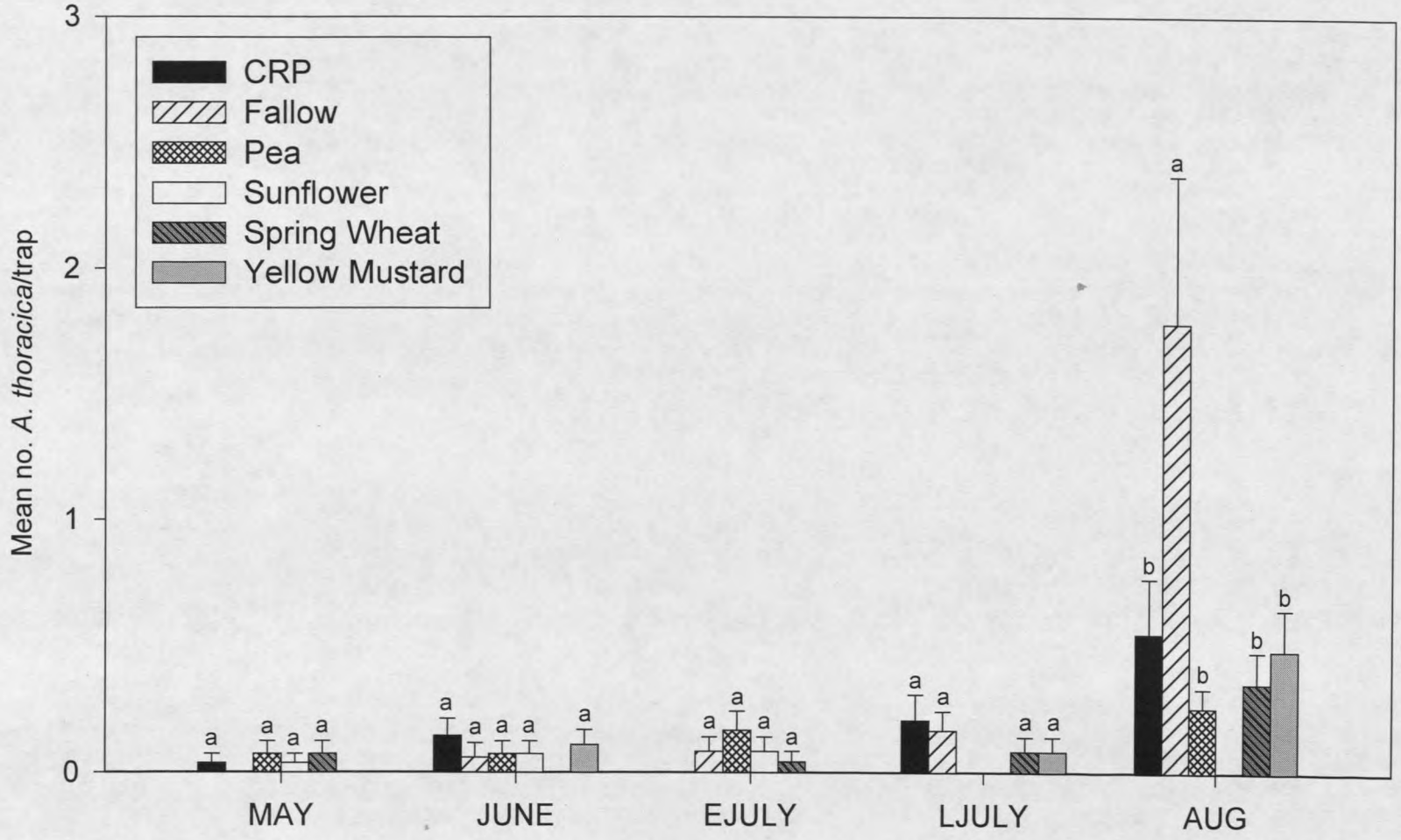
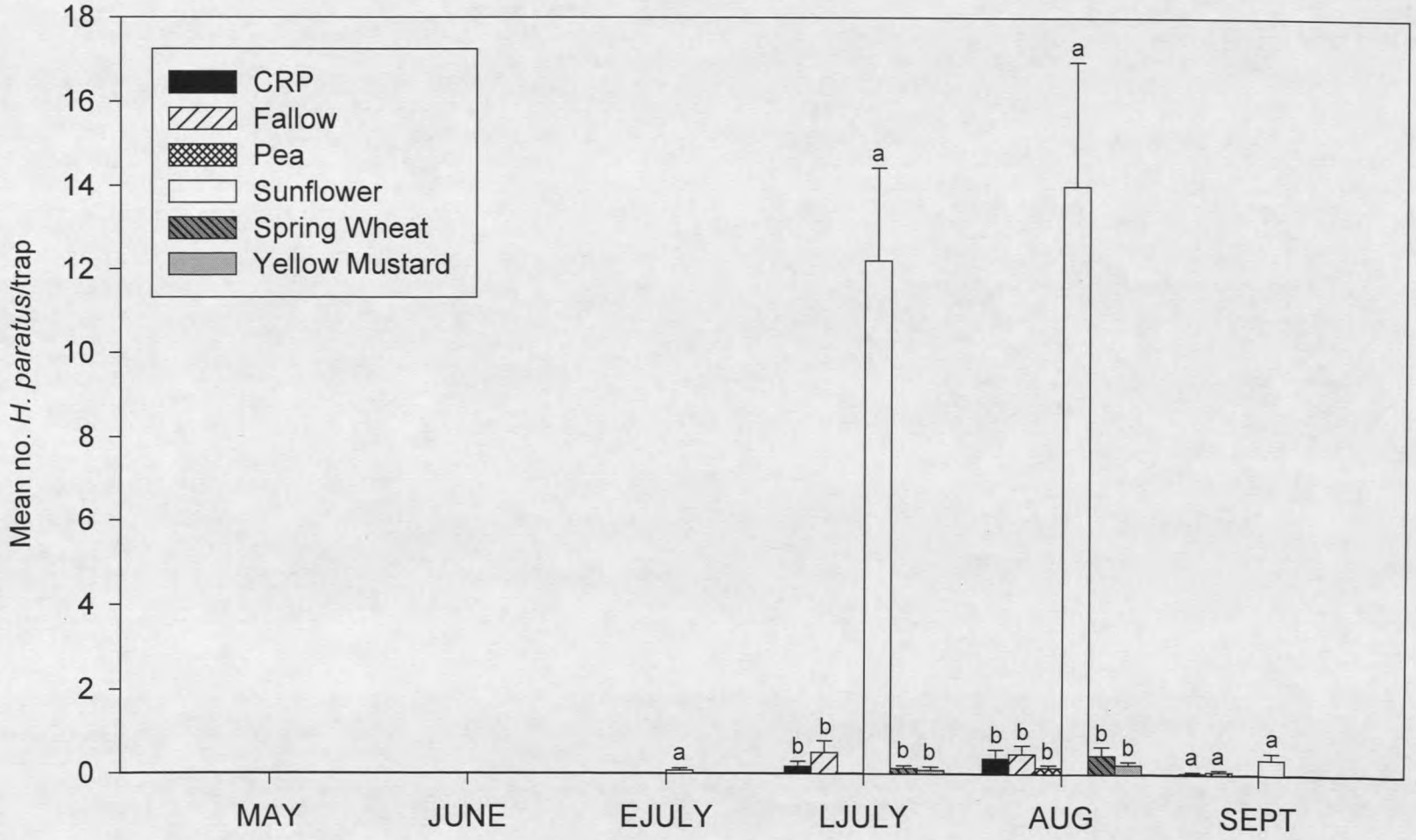


Figure 28. Mean number of *Harpalus paratus* per trap in CRP, fallow, pea, sunflower, spring wheat, and yellow mustard, for six sampling dates, including two periods in July (EJULY and LJULY, early and late July, respectively). Different letters indicate significant differences ($p<0.05$). 1998.



Other species

Similar analyses were performed for other individual species, including *Calosoma lepidum*, *Harpalus reversus*, *Amara obesa*, and *Pasimachus elongatus*. None of these species exhibited recognizable patterns in their activity in relation to crops. These species appear to be crop type generalists.

# CHAPTER 5

# DISCUSSION

## Pitfall Traps

Pitfall traps are the standard method used for collecting carabid beetles because they are labor efficient and relatively inexpensive to construct. However, scientific opinion differs regarding the effectiveness of these traps for measuring carabid species densities and abundance. Southwood (1966) concluded, "pitfall traps are of little value for the direct estimation of populations or for the comparison of communities." Several other studies show that trap efficacy depends upon several variables: temperature, humidity, surrounding vegetation, and number, size, shape, and arrangement of traps (Greenslade 1964, Luff 1975, Baars 1979, Morrill et al. 1990, Spence and Niemelä 1994). The limitation of pitfall traps is that they measure what Thiele (1977) calls "activity-density". These traps are passive, and rely on the movement of carabids within the study area for capture. There are no baits or other attractants placed in the traps, so beetles must simply be active in the sample area and fall in the trap. Thus the traps measure only those species that are active (Thiele 1977). With these limitations in mind, pitfall traps have been used to compare carabid species activity or to census carabid activity within a variety of habitats such as different cropping systems. Numbers of a

certain species in a trap can provide information regarding their densities over time and space.

## All Carabid Species

In both years, the May sampling date showed no significant differences in carabid numbers among crops. All crops during this sampling period were at early vegetative developmental stages. Towards the end of the month of May and the beginning of June, with rapid degree day accumulation, crops began growing exponentially. By mid-June, peas and yellow mustard were in the early bud stage. Spring wheat was beginning to elongate, and sunflower remained in a vegetative stage. By the end of June to the beginning of July, yellow mustard was in flowering and early pod formation stages. Degree day accumulation among crops began to diverge in June, with noticeably reduced heat accumulation at the soil surface under yellow mustard canopy (Figures 16 and 17). In addition, relative humidity was greater in the yellow mustard canopy, compared with the rest of the crops (Figures 18 and 19).

Although differences in degree day accumulation and relative humidity were observed among crops, it is unlikely that these differences, although they may have favored activity, were responsible for the dramatic differences in carabid activity in yellow mustard compared to other crops. Activity of *H. fuscipalpis* was significantly greater in yellow mustard, suggesting a direct or indirect association with this crop. Prey species availability, although not investigated, may have been an important factor in

activity level. Potential yellow mustard specialist insect pests (diamondback moth larvae and flea beetles) were detected in this crop (M. Rolston, unpublished data, Montana State University) and may have influenced carabid activity.

The lack of tillage effect in 1998 may be attributed to the fact that this was the first year of the study and tillage effects may not have accumulated by this time. Studies that show tillage effects on carabid beetles are usually from long term studies where no-till plots have been established for several years (House and Crossley 1987, House and Stinner 1987, Stinner et al. 1988). Many studies suggest that carabids prefer the increased amount of organic matter and crop residues in no-till systems that accumulate over time (House and All 1981, House and Stinner 1983, House and Crossley 1987, Weiss et al. 1990). Since 1998 was the initial year of the Sustainable Pest Management study, there were no cumulative surface residues or increased soil organic matter in these plots. In 1999, there was a tillage effect on total carabid activity with no-till having greater numbers of carabid beetles in the late July sampling date only. No-till plots may have retained moisture because of the surface residues in the plots and lack of disturbance which enhances soil moisture loss (A. Lenssen, pers. com., Montana State University). In mid-July, carabids may have preferred the greater soil moisture in the no-till plots over the drier tilled plots. It is more likely, however, that the high activity level of *H. fuscipalpis* in no-till yellow mustard plots influenced the significant tillage by date interaction.

Individual Carabid Species

The results of the analysis on *Harpalus fuscipalpis* show a strong association with yellow mustard. This species was collected in large numbers both years and was consistently found in yellow mustard more than any other crop. This species did not start appearing in traps until the June sample date, when yellow mustard was beginning to flower and was present through September in 1998 and August in 1999. This species' association with no-till yellow mustard plots could be influential on the tillage effect that was observed for all carabid species combined (see Figure 15).

The strong association between *H. fuscipalpis* and yellow mustard could be caused by several factors. Yellow mustard had slower degree day accumulation and greater relative humidity at ground level than the rest of the crops. It is possible that *H. fuscipalpis* prefers this difference in microclimatic conditions at the ground level. However, several specialist prey species were present in this crop, so the association may be indirectly related to their presence. Members of the genus *Harpalus* are often classified as being at least partially phytophagous, so the association with yellow mustard could be due to a weed population. However, it is not likely that this species was feeding on yellow mustard seed since *H. fuscipalpis* activity began to peak in July and yellow mustard was still flowering and just beginning to form pods and no plant feeding was evident. *Amara littoralis* also showed an association with yellow mustard, although the general activity level of this species was not as great as *H. fuscipalpis*.

In 1998, arthropods present in yellow mustard treatments consisted of 52% Chrysomelidae (flea beetles), 24% Plutellidae (diamondback moth larvae), 6% Miridae, 4% Cicadellidae, and 1% Aphididae (M. Rolston, unpublished data, Montana State University). In 1999, there was a similar arthropod complex consisting of 52% Plutellidae (diamondback moth larvae), 28% Miridae, and 11% Chrysomelidae (flea beetles). In both years, yellow mustard was the only crop in which populations of diamondback moth larvae and flea beetles were detected. A few flea beetles were also collected in CRP in 1998. It is possible that *H. fuscipalpis* was feeding preferentially on one or both of these insects.

Two species were active in sunflower plots. *Amara thoracica* and *Harpalus paratus* were associated with sunflower in late July and August in 1998. Sunflower plots tended to have high populations of Russian thistle (*Salsola iberica* Sennen) and kochia (*Kochia scoparia* (L.) Schrad). High populations of these weeds in sunflower in 1999 resulted in termination of the pea – spring wheat – sunflower rotation after 1 July. In addition, late in the season (August), fallow plots tended to have higher populations of both of these weed species. Members of the genera *Amara* and *Harpalus* are usually classified as being spermophagous, so high densities of these weeds could have caused these species to be attracted to the sunflower plots in 1998 and also to the fallow plots in August 1999.

However, there were species collected in this study that did not have the strong crop associations exhibited by *H. fuscipalpis*, *A. littoralis*, *A. thoracica*, and *H. paratus*. *Microlestes linearis*, *Calosoma lepidum*, *Harpalus reversus*, *Amara obesa*, and

*Pasimachus elongatus* seemed to be generalists in terms of an association with a particular crop type, not found consistently in one crop over time. However, *M. linearis* numbers were always greater in the till treatment (June, late July, and August).

# CHAPTER 6

# CONCLUSIONS

In general, yellow mustard supported the greatest populations of carabid beetles, primarily due to *Harpalus fuscipalpis* that were collected in high numbers. 62% and 84% of the carabids collected in yellow mustard were *H. fuscipalpis* in 1998 and 1999, respectively. Sunflower supported two crop specialists, *Harpalus paratus* and *Amara thoracica* late in the growing season. which may be been an indirect association with kochia and Russian thistle, two dominant weed species in those plots.

*H. fuscipalpis* is a crop type specialist, occurring almost exclusively in yellow mustard. Several factors could be influencing its preference for this crop, including microclimatic factors such as temperature and humidity and prey availability. Further research on this species and other potential crop specialists such as *Amara littoralis*, *Harpalus paratus* and *Amara thoracica* would be beneficial. Feeding trials would help determine whether prey preference or environmental conditions determine the crop preferences observed. It may also be beneficial to conduct preference tests with crops to see if the beetles are attracted to volatile chemicals given off by the mustard.

Additional data should be collected in sunflower plots, because it seems that *H. paratus* and perhaps *A. thoracica* were exhibiting a close association with this crop, or an indirect association with the weeds found in these plots. It is difficult to draw conclusions from only one year of data, however.

# LITERATURE CITED

Allen, W. A. and E. G. Rajotte. 1990. The changing role of extension entomology in the IPM era. *Ann. Rev. Entomol.* 35: 379-397.

Baars, M. A. 1979. Catches in pitfall traps in relation to mean densities of carabid beetles. *Oecologia* 41: 25-46.

Baines, D., R. Stewart and G. Boivin. 1990. Consumption of carrot weevil (Coleoptera: Curculionidae) by five species of carabids (Coleoptera: Carabidae) abundant in carrot fields in southwestern Quebec. *Environ. Entomol.* 19: 1146-1149.

Ball, G. E. 1968. Carabidae. pp. 55-182 in R. H. Arnett, ed. *The Beetles of the United States (A manual for identification)*. The American Entomological Institute, Ann Arbor, MI.

Barney, R. J. and B. C. Pass. 1986a. Foraging behavior and feeding preference of ground beetles (Coleoptera: Carabidae) in Kentucky Alfalfa. *J. Econ. Entomol.* 79: 1334-1337.

Barney, R. J. and B. C. Pass. 1986b. Ground beetle (Coleoptera: Carabidae) populations in Kentucky alfalfa and influence of tillage. *J. Econ. Entomol.* 79: 511-517.

Best, R. L. and C. C. Beegle. 1977a. Consumption of *Agrotis ipsilon* by several species of carabids found in Iowa. *Environ. Entomol.* 6: 532-534.

Best, R. L. and C. C. Beegle. 1977b. Food preferences of five species of carabids commonly found in Iowa cornfields. *Environ. Entomol.* 6: 9-12.

Bilde, T. and S. Toft. 1999. Prey consumption and fecundity of the carabid beetle *Calathus melanocephalus* on diets of three cereal aphids: high consumption rates of low-quality prey. *Pedobiologia* 43: 422-429.

Blumberg, A. Y. and D. A. Crossley, Jr. 1983. Comparison of soil surface arthropod populations in conventional tillage, no-tillage, and old field systems. *Agro-Ecosystems* 8: 247-253.

Blumberg, A. Y. and D. A. Crossley, Jr. 1988. Diurnal activity of soil-surface arthropods in agroecosystems: Design for an inexpensive time-sorting pitfall trap. *Agric. Ecosyst. Environ.* 20: 159-164.

Bousquet, Y. and A. Larochelle. 1993. Catalogue of the Geadephaga (Coleoptera: Trachypachidae, Rhysodidae, Carabidae including Cicindelini) of America North of Mexico. *Memoirs of the Entomological Sociéty of Canada* 167: 1-397.

Brandmayr, T. Z. 1990. Spermophagous (seed-eating) ground beetles: first comparison of the diet and ecology of the Harpaline genera *Harpalus* and *Ophonus* (Col., Carabidae). pp. 307-316 in N. E. Stork, ed. *The Role of Ground Beetles in Ecological and Environmental Studies*. Intercept Ltd., Andover, Hampshire.

Brust, G. E., B. R. Stinner and D. A. McCartney. 1985. Tillage and soil insecticide effects on predator - black cutworm (Lepidoptera: Noctuidae) interactions in corn agroecosystems. *J. Econ. Entomol.* 78: 1389-1392.

Brust, G. E., B. R. Stinner and D. A. McCartney. 1986. Predator activity and predation in corn agroecosystems. *Environ. Entomol.* 15: 1017-1021.

Bugg, R. L. and C. H. Pickett. 1998. Introduction: Enhancing biological control - habitat management to promote natural enemies of agricultural pests. pp. 1-23 in R. L. Bugg and C. H. Pickett, eds. *Enhancing Biological Control: Habitat management to promote natural enemies of agricultural pests*. University of California Press, Berkeley.

Burton, R. L. and J. D. Burd. 1994. Effects of surface residues on insect dynamics. pp. 245-260 in P. W. Unger, ed. *Managing Agricultural Residues*. Lewis Publishers, Boca Raton.

Cárcamo, H. A. 1995. Effect of tillage on ground beetles (Coleoptera: Carabidae): a farm-scale study in Central Alberta. *Can. Entomol.* 127: 631-639.

Cárcamo, H. A. and J. R. Spence. 1994. Crop type effects on the activity and distribution of ground beetles (Coleoptera: Carabidae). *Environ. Entomol.* 23: 684-692.

Carlson, G. and A. Lenssen. 1999. Agronomic practices and crop yield and quality. pp. 5-12. *Sustainable Pest Management in Dryland Wheat, USDA Special Grant, 1999 Annual Report, Havre site*. Montana State University, Bozeman, MT.

Chiverton, P. A. and N. W. Sotherton. 1991. The effects on beneficial arthropods of the exclusion of herbicides from cereal crop edges. *J. Appl. Ecol.* 28: 1027-1039.

Clark, M. S., S. H. Gage and J. R. Spence. 1997. Habitats and management associated with common ground beetles (Coleoptera: Carabidae) in a Michigan agricultural landscape. *Environ. Entomol.* 26: 519-527.

Clark, M. S., J. M. Luna, et al. 1993. Habitat preferences of generalist predators in reduced -tillage corn. *Journal of Entomological Science* 28: 404-416.

Clark, M. S., J. M. Luna, et al. 1994. Generalist predator consumption of armyworm (Lepidoptera: Noctuidae) and effect of predator removal on damage in no-till corn. *Environ. Entomol.* 23: 617-622.

DeBach, P. 1964. *Biological control of insect pests and weeds*. Reinhold Publishing Corporation, New York.

den Boer, P. J. and W. den Boer-Daanje. 1990. On life history tactics in carabid beetles: are there only spring and autumn breeders? pp. 247-258 in N. E. Stork, ed. *The Role of Ground Beetles in Ecological and Environmental Studies*. Intercept, Ltd., Andover, Hampshire.

Domitruk, D., B. Crabtree, et al., eds. 1997. *Zero-Tillage: Advancing the Art*. Manitoba-North Dakota Zero Tillage Farmers Association, Manitoba.

Dülge, R. 1994. Seasonal activity of carabid beetles in wooded habitats in northwest Germany (Coleoptera: Carabidae). pp. 125-131 in K. Desender, M. Dufrene, M. Loreau, M. L. Luff, and J.-P. Maelfait, eds. *Carabid Beetles: Ecology and Evolution*. Kluwer Academic Publishers, Dordrecht.

Edwards, C. A. and K. S. George. 1981. Carabids as predators of cereal aphids. pp. 191-199. *British Crop Protection Conference - Pests and Diseases*. The British Crop Protection Council, Lavenhayn Press Ltd., Brighton, England.

Edwards, C. A., K. D. Sunderland and K. S. George. 1979. Studies on polyphagous predators of cereal aphids. *J. Appl. Ecol.* 16: 811-823.

Evans, M. E. G. 1994. The carabid body plan: a functional interpretation. pp. 25-31 in K. Desender, M. Dufrene, M. Loreau, M. L. Luff, and J.-P. Maelfait, eds. *Carabid Beetles: Ecology and Evolution*. Kluwer Academic Publishers, Dordrecht.

Fadl, A. and G. Purvis. 1998. Field observations on the lifecycles and seasonal activity patterns of temperate carabid beetles (Coleoptera: Carabidae) inhabiting arable land. *Pedobiologia* 42: 171-183.

Floate, K. D., J. F. Doane and C. Gillott. 1990. Carabid predators of the wheat midge (Diptera: Cecidomyiidae) in Saskatchewan. *Environ. Entomol.* 19: 1503-1511.

Forsythe, T. G. 1982. Feeding mechanisms of certain ground beetles (Coloeptera: Carabidae). *Coleopterists Bulletin* 36: 26-73.

Frank, J. H. 1971. Carabidae (Coleoptera) as predators of the redbacked cutworm (Lepidoptera: Noctuidae) in central Alberta. *Can. Entomol.* 103: 1039-1044.

Greenslade, P. J. M. 1964. Pitfall trapping as a method for studying populations of Carabidae (Coleoptera). *The Journal of Animal Ecology* 33: 301-310.

Hammond, R. B. 1987. Pest management in reduced-tillage soybean cropping systems. pp. 19-28 in G. J. House and B. R. Stinner, eds. *Arthropods in Conservation Tillage Systems*. Entomological Society of America, College Park, MD.

Hance, T. 1987. Predation impact of carabids at different population densities on *Aphis fabae* development in sugar beet. *Pedobiologia* 30: 251-262.

Hance, T. and C. Grégoire-Wibo. 1987. Effect of agricultural practices on carabid populations. *Acta Phytopathol. Entomol. Hung.* 22: 147-160.

Hance, T., C. Grégoire-Wibo and P. Lebrun. 1990. Agriculture and ground beetle populations: The consequence of crop types and surrounding habitats on activity and species composition. *Pedobiologia* 34: 337-346.

House, G. J. 1989. Soil arthropods from weed and crop roots of an agroecosystem in an wheat-soybean-corn rotation: impact of tillage and herbicides. *Agric. Ecosyst. Environ.* 25: 233-244.

House, G. J. and J. N. All. 1981. Carabid beetles in soybean agroecosystems. *Environ. Entomol.* 10: 194-196.

House, G. J. and G. E. Brust. 1989. Ecology of low-input, no-tillage agroecosystems. *Agric. Ecosyst. Environ.* 27: 331-345.

House, G. J. and D. A. Crossley, Jr. 1987. Legume cover cropping, no-till practices, and soil arthropods: ecological interactions and economic significance. pp. 68-69 in J. F. Power, ed. *The role of legumes in conservation tillage systems*. Soil Conservation Society of America, Ankeny, Iowa.

House, G. J. and M. Del Rosario Alzugaray. 1989. Influence of cover cropping and no-tillage practices on community composition of soil arthropods in a North Carolina agroecosystem. *Environ. Entomol.* 18: 302-307.

House, G. J. and R. W. Parmalee. 1985. Comparison of soil arthropods and earthworms from conventional and no-tillage agroecosystems. *Soil and Tillage Research* 5: 351-360.

House, G. J. and B. R. Stinner. 1983. Arthropods in no-tillage soybean agroecosystems: Community composition and ecosystem interactions. *Environmental Management* 7: 23-28.

House, G. J. and B. R. Stinner. 1987. Influence of soil arthropods on nutrient cycling in no-tillage agroecosystems. pp. 44-52 in G. J. House and B. R. Stinner, eds. *Arthropods in Conservation Tillage Systems*. Entomological Society of America, College Park, MD.

Johnson, G. 1999. Sustainable pest management in dryland wheat. pp. 3-4. *Sustainable Pest Management in Dryland Wheat, USDA Special Grant, 1999 Annual Report, Havre site*. Montana State University, Bozeman, MT.

Johnson, N. E. and R. S. Cameron. 1969. Phytophagous ground beetles. *Annals of the Entomological Society of America* 62: 909-914.

Jones, M. G. 1979. The abundance and reproductive activity of common Carabidae in a winter wheat crop. *Ecological Entomology* 4: 31-43.

Jørgensen, H. B. and S. Toft. 1997. Food preference, diet dependent fecundity and larval development in *Harpalus rufipes* (Coleoptera: Carabidae). *Pedobiologia* 41: 307-315.

Kegel, B. 1990. Diurnal activity of carabid beetles living on arable land. pp. 65-76 in N. E. Stork, ed. *The Role of Ground Beetles in Ecological and Environmental Studies*. Intercept, Ltd., Andover, Hampshire.

Kielty, J. P., L. J. Allen-Williams and N. Underwood. 1999. Prey preferences of six species of Carabidae (Coleoptera) and one Lycosidae (Araneae) commonly found in UK arable crop fields. *Zeitschrift fur angewandte Entomologie* 123: 193.

Larochelle, A. 1990. The food of carabid beetles (Coleoptera: Carabidae, including Cicindelinae). *Fabreries, Supplément* 5: 1-132.

Laub, C. A. and J. M. Luna. 1992. Winter cover crop suppression practices and natural enemies of armyworm (Lepidoptera: Noctuidae) in no-till corn. *Environ. Entomol.* 21: 41-49.

Lindroth, C. H. 1961-69. The ground beetles (Carabidae, exc. Cicindelinae) of Canada and Alaska Parts 1-6. *Opuscula Entomologica* xlvii: 1192 pp.

Lövei, G. L. and K. D. Sunderland. 1996. Ecology and behavior of ground beetles (Coleoptera: Carabidae). *Ann. Rev. Entomol.* 41: 231-56.

Luff, M. L. 1975. Some features influencing the efficiency of pitfall traps. *Oecologia* 19: 345-357.

Luff, M. L. 1987. Biology of polyphagous ground beetles in agriculture. *Agricultural Zoology Reviews* 2: 237-278.

Lund, R. D. and F. T. Turpin. 1977a. Carabid damage to weed seeds found in Indiana cornfields. *Environ. Entomol.* 6: 695-698.

Lund, R. D. and F. T. Turpin. 1977b. Serological investigation of black cutworm larval consumption by ground beetles. *Annals of the Entomological Society of America* 70: 322-324.

Lys, J.-A. 1994. The positive influence of strip-management on ground beetles in a cereal field: increase, migration, and overwintering. pp. 451-455 in K. Desender, M. Dufrene, M. Loreau, M. L. Luff, and J.-P. Maelfait, eds. *Carabid Beetles: Ecology and Evolution.* Kluwer Academic Publishers, Dordrecht.

Lys, J.-A. and W. Nentwig. 1991. Surface activity of carabid beetles inhabiting cereal fields: Seasonal phenology and the influence of farming operations on five abundant species. *Pedobiologia* 35: 129-138.

Lys, J.-A. and W. Nentwig. 1992. Augmentation of beneficial arthropods by strip-management: 4. Surface activity, movements, and activity density of abundant carabid beetles in a cereal field. *Oecologia* 92: 373-382.

Lys, J.-A., M. Zimmermann and W. Nentwig. 1994. Increase in activity density and species number of carabid beetles in cereals as a result of strip-management. *Entomol. Exp. Appl.* 73: 1-9.

Mack, T. P. and C. B. Backman. 1990. Effects of two planting dates and three tillage systems on the abundance of yield lesser cornstalk borer (Lepidoptera: Pyralidae), other selected insects, and yield in peanut fields. *J. Econ. Entomol.* 83: 1034-1041.

Makarov, K. V. 1994. Annual reproduction rhythms of ground beetles: a new approach to the old problem. pp. 177-182 in K. Desender, M. Dufrene, M. Loreau, M. L. Luff, and J.-P. Maelfait, eds. *Carabid Beetles: Ecology and Evolution.* Kluwer Academic Publishers, Dordrecht.

Menalled, F. D., P. C. Marino, et al. 2000. Post-dispersal weed seed predation in Michigan crop fields as a function of agricultural landscape structure. *Agric. Ecosyst. Environ.* 77: 193-202.

Morrill, W. L., D. G. Lester and A. E. Wrona. 1990. Factors affecting efficacy of pitfall traps for beetles (Coleoptera: Carabidae and Tenebrionidae). *Journal of Entomological Science* 25: 284-293.

Norris, R. F. and M. Kogan. 2000. Interactions between weeds, arthropod pests, and their natural enemies in managed ecosystems. *Weed Science* 48: 94-158.

Pavuk, D. M., F. F. Purrington, et al. 1997. Ground beetle (Coleoptera: Carabidae) activity density and community composition in vegetationally diverse corn agroecosystems. *Am. Midl. Nat.* 138: 14-28.

Riddick, E. W. and N. J. Mills. 1994. Potential of adult carabids (Coleoptera: Carabidae) as predators of fifth-instar codling moth (Lepidoptera: Tortricidae) in apple orchards in California. *Environ. Entomol.* 23: 1338-1345.

Rivard, I. 1966. Ground beetles (Coleoptera: Carabidae) in relation to agricultural crops. *Can. Entomol.* 98: 189-195.

Russell, E. P. 1989. Enemies hypothesis: A review of the effect of vegetational diversity on predatory insects and parasitoids. *Environ. Entomol.* 18: 590-599.

Sheehan, W. 1986. Response by specialist and generalist natural enemies to agroecosystem diversification: A selective review. *Environ. Entomol.* 15: 456-461.

Shelton, M. D. and C. R. Edwards. 1983. Effects of weeds on the diversity and abundance of insects in soybeans. *Environmental Entomologist* 12: 296-283.

Southwood, T. R. E. 1966. *Ecological Methods with particular reference to the study of insect populations*. Methuen, London.

Spence, J. R. and J. K. Niemelä. 1994. Sampling carabid assemblages with pitfall traps: the madness and the method. *Can. Entomol.* 126: 881-894.

Stinner, B. R., D. A. McCartney and D. M. J. Van Doren. 1988. Soil and foliage arthropod communities in conventional, reduced, and no-tillage corn (Maize, *Zea mays* L.) systems: a comparison after 20 years of continuous cropping. *Soil and Tillage Research* 11: 147-158.

Suenaga, H. and T. Hamamura. 1998. Laboratory evaluation of carabid beetles (Coleoptera: Carabidae) as predators of diamondback moth (Lepidoptera: Plutellidae) larvae. *Environ. Entomol.* 27: 767-772.

Thiele, H.-U. 1977. *Carabid Beetles in Their Environments*. Springer-Verlag, Berlin.

Tonhasca, A., Jr. 1993. Carabid beetle assemblage under diversified agricultural systems. *Entomol. Exp. Appl.* 68: 279-285.

Tonhasca, A., Jr. and B. R. Stinner. 1991. Effects of strip intercropping and no-tillage on some pests and beneficial invertebrates of corn in Ohio. *Environ. Entomol.* 20: 1251-1258.

Weiss, M. J., E. U. Balsbaugh, Jr., et al. 1990. Influence of tillage management and cropping system on ground beetle (Coleoptera: Carabidae) fauna in the Northern Great Plains. *Environ. Entomol.* 19: 1388-1391.

Winder, L. 1990. Predation of the cereal aphid *Sitobion avenae* by polyphagous predators on the ground. *Ecological Entomology* 15: 105-110.

Young, F. L., A. G. Ogg and R. I. Papendick. 1994. Tillage and weed management affects winter wheat yield in an integrated pest management system. *Agronomy Journal* 86: 147-154.

Zangger, A. 1994. The positive influence of strip-management on carabid beetles in a cereal field: accessibility of food and reproduction in *Poecilus cupreus*. pp. 469-472 in K. Desender, M. Dufrene, M. Loreau, M. L. Luff, and J.-P. Maelfait, eds. *Carabid Beetles: Ecology and Evolution*. Kluwer Academic Publishers, Dordrecht.

Zangger, A., J.-A. Lys and W. Nentwig. 1994. Increasing the availability of food and the reproduction of *Poecilus cupreus* in a cereal field by strip-management. *Entomol. Exp. Appl.* 71: 111-120.

# APPENDICES

# APPENDIX A

Species Names in Lindroth's keys (1961-69)
and updated species names from Bousquet
and Larochelle's catalog (1993).

| **Lindroth (1961-69)** | **Bousquet and Larochelle (1993)** |
|---|---|
| *Agonum cupreum* Dejean | *Agonum cupreum* Dejean |
| *Agonum placidum* (Say) | *Agonum placidum* (Say) |
| *Amara apricaria* (Paykull) | *Amara apricaria* (Paykull) |
| *Amara littoralis* Mannerheim | *Amara littoralis* Mannerheim |
| *Amara obesa* (Say) | *Amara obesa* (Say) |
| *Amara quenseli* (Schonherr) | *Amara quenseli* (Schonherr) |
| *Amara thoracica* Hayward | *Amara thoracica* Hayward |
| *Anisodactylus sanctaecrucis* (Fabricius) | *Anisodactylus sanctaecrucis* (Fabricius) |
| *Bembidion nitidum* (Kirby) | *Bembidion nitidum* (Kirby) |
| *Bembidion nudipenne* Lindroth | *Bembidion nudipenne* Lindroth |
| *Bembidion obscurellum* (Motschulsky) | *Bembidion obscurellum* (Motschulsky) |
| *Bembidion quadrimaculatum* Linné | ***Bembidion quadrimaculatum dubitans* (LeConte)** |
| *Bembidion rapidum* (LeConte) | *Bembidion rapidum* (LeConte) |
| *Bembidion versicolor* (LeConte) | *Bembidion versicolor* (LeConte) |
| *Bradycellus congener* (LeConte) | *Bradycellus congener* (LeConte) |
| *Calleida viridis* Dejean | ***Calleida caerulea* (Casey)** |
| *Calosoma lepidum* LeConte | *Calosoma lepidum* LeConte |
| *Calosoma luxatum* Say | *Calosoma luxatum* Say |
| *Calosoma obsoletum* Say | *Calosoma obsoletum* Say |
| *Chlaenius sericeus* (Forster) | ***Chlaenius sericeus sericeus* (Forster)** |
| *Cicindela limbalis* Klug | *Cicindela limbalis* Klug |
| *Cicindela punctulata* Olivier | ***Cicindela punctulata punctulata* Olivier** |
| *Cicindela purpurea* (Olivier) | *Cicindela purpurea audubonii* LeConte |
| *Cratacanthus dubius* (Palisot de Beauvois) | *Cratacanthus dubius* (Palisot de Beauvois) |
| *Cymindis borealis* LeConte | *Cymindis borealis* LeConte |
| *Cymindis planipennis* LeConte | *Cymindis planipennis* LeConte |
| *Dyschirius globulosus* (Say) | *Dyschirius globulosus* (Say) |
| *Harpalus amputatus* (Say) | *Harpalus amputatus* Say |
| *Harpalus bicolor* Fabricius | ***Harpalus compar* LeConte** |
| *Harpalus desertus* LeConte | *Harpalus desertus* LeConte |
| *Harpallelus basilaris* Kirby | ***Harpalus fuscipalpus* Sturm** |
| *Harpalus opacipennis* (Haldeman) | *Harpalus opacipennis* (Haldeman) |
| *Harpalus paratus* Casey | *Harpalus paratus* Casey |
| *Harpalus funerarius* Csiki | ***Harpalus reversus* Casey** |
| *Harpalus somnulentus* Dejean | *Harpalus somnulentus* Dejean |
| *Harpalus ventralis* LeConte | *Harpalus ventralis* LeConte |
| *Lebia atriceps* LeConte | *Lebia atriceps* LeConte |
| *Lebia solea* Hentz | *Lebia solea* Hentz |
| *Microlestes linearis* (LeConte) | *Microlestes linearis* (LeConte) |
| *Pasimachus elongatus* LeConte | *Pasimachus elongatus* LeConte |
| *Piosoma setosum* LeConte | *Piosoma setosum* LeConte |
| *Pterostichus corvus* LeConte | ***Poecilus corvus* (LeConte)** |
| *Pterostichus lucublandus* Say | ***Poecilus lucublandus* (Say)** |
| *Pterostichus scitulus* LeConte | ***Poecilus scitulus* LeConte** |
| *Stenolophus comma* (Fabricius) | *Stenolophus comma* (Fabricius) |

# APPENDIX B

Total Number of Carabid Beetles
Collected in Each Crop Type
and Tillage Treatment, 1998

| | CRP | | Fallow | | Pea | | Sunflower | | Spring Wheat | | Yellow Mustard | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Species** | **No Till** | **Till** | **No Till** | **Till** | **No Till** | **Till** | **No Till** | **Till** | **No Till** | **Till** | **No Till** | **Till** |
| *Agonum cupreum* | 2 | 0 | 2 | 0 | 4 | 7 | 2 | 1 | 4 | 16 | 17 | 17 |
| *Agonum placidum* | 3 | 2 | 2 | 1 | 5 | 6 | 2 | 1 | 9 | 20 | 18 | 23 |
| *Amara apricaria* | 0 | 1 | 0 | 4 | 1 | 1 | 11 | 8 | 1 | 0 | 0 | 3 |
| *Amara littoralis* | 7 | 13 | 1 | 1 | 8 | 1 | 9 | 11 | 3 | 5 | 130 | 134 |
| *Amara obesa* | 84 | 84 | 48 | 236 | 30 | 56 | 49 | 97 | 31 | 95 | 29 | 62 |
| *Amara quenseli* | 7 | 8 | 1 | 1 | 2 | 1 | 21 | 33 | 4 | 1 | 4 | 7 |
| *Amara thoracica* | 84 | 61 | 29 | 127 | 22 | 27 | 137 | 78 | 38 | 133 | 43 | 28 |
| *Anisodactylus sanctaecrucis* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Bembidion nitidum* | 5 | 14 | 9 | 29 | 4 | 15 | 8 | 27 | 11 | 12 | 7 | 12 |
| *Bembidion nudipenne* | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Bembidion obscurellum* | 1 | 0 | 0 | 10 | 0 | 2 | 0 | 2 | 0 | 2 | 0 | 1 |
| *Bembidion quadrimaculatum* | 0 | 0 | 0 | 5 | 1 | 1 | 0 | 5 | 1 | 5 | 0 | 0 |
| *Bembidion rapidum* | 0 | 7 | 5 | 7 | 9 | 2 | 6 | 7 | 13 | 6 | 19 | 9 |
| *Bembidion versicolor* | 24 | 6 | 13 | 21 | 10 | 5 | 6 | 10 | 16 | 9 | 2 | 8 |
| *Bradycellus conger* | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 4 | 1 |
| *Calleida viridis* | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 |
| *Calosoma lepidum* | 24 | 30 | 7 | 8 | 17 | 24 | 36 | 29 | 31 | 26 | 32 | 35 |
| *Calosoma luxatum* | 4 | 3 | 1 | 2 | 1 | 3 | 0 | 2 | 0 | 4 | 3 | 4 |
| *Calosoma obsoletum* | 19 | 14 | 3 | 5 | 2 | 3 | 8 | 12 | 9 | 10 | 59 | 28 |
| *Chlaenius sericeus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| *Cicindela limbalis* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| *Cicindela punctulata* | 4 | 0 | 3 | 2 | 1 | 1 | 1 | 3 | 0 | 1 | 2 | 2 |
| *Cicindela purpurea* | 0 | 0 | 4 | 2 | 1 | 5 | 0 | 1 | 0 | 0 | 2 | 1 |
| *Cratacanthus dubius* | 1 | 2 | 3 | 0 | 0 | 0 | 4 | 0 | 1 | 1 | 0 | 0 |
| *Cymindis borealis* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Cymindis planipennis* | 6 | 3 | 2 | 5 | 1 | 6 | 4 | 4 | 1 | 0 | 0 | 2 |
| *Dyschirius globulosus* | 10 | 7 | 9 | 13 | 7 | 8 | 1 | 11 | 15 | 14 | 8 | 10 |
| *Harpalus amputatus* | 6 | 6 | 8 | 12 | 6 | 8 | 7 | 22 | 3 | 10 | 7 | 27 |
| | **CRP** | | **Fallow** | | **Pea** | | **Sunflower** | | **Spring Wheat** | | **Yellow Mustard** | |

| Species | No Till | Till | No Till | Till | No Till | Till | No Till | Till | No Till | Till | No Till | Till |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Harpalus compar* | 1 | 0 | 0 | 3 | 1 | 1 | 19 | 2 | 0 | 1 | 2 | 1 |
| *Harpalus desertus* | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 6 | 7 |
| *Harpalus fuscipalpis* | 11 | 44 | 17 | 24 | 167 | 27 | 20 | 24 | 35 | 56 | 1522 | 1873 |
| *Harpalus opacipennis* | 2 | 0 | 0 | 0 | 1 | 2 | 0 | 1 | 0 | 2 | 0 | 1 |
| *Harpalus paratus* | 14 | 1 | 22 | 5 | 1 | 3 | 430 | 260 | 3 | 12 | 3 | 5 |
| *Harpalus reversus* | 66 | 57 | 17 | 23 | 7 | 8 | 22 | 34 | 13 | 30 | 8 | 16 |
| *Harpalus somnulentus* | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Harpalus ventralis* | 2 | 5 | 3 | 0 | 2 | 4 | 3 | 7 | 9 | 34 | 6 | 7 |
| *Lebia atriceps* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| *Lebia solea* | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Microlestes linearis* | 67 | 53 | 7 | 30 | 17 | 39 | 12 | 37 | 53 | 54 | 17 | 39 |
| *Pasimachus elongatus* | 18 | 47 | 8 | 10 | 18 | 31 | 15 | 26 | 52 | 36 | 46 | 52 |
| *Piosoma setosum* | 1 | 3 | 6 | 12 | 2 | 6 | 3 | 2 | 0 | 1 | 1 | 5 |
| *Poecilus corvus* | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 2 | 0 | 1 | 0 | 0 |
| *Poecilus lucublandus* | 1 | 1 | 1 | 1 | 3 | 1 | 3 | 2 | 9 | 13 | 14 | 2 |
| *Poecilus scitulus* | 2 | 9 | 3 | 10 | 6 | 1 | 0 | 1 | 6 | 8 | 3 | 7 |
| *Stenolophus comma* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| ***TOTAL*** | **479** | **483** | **235** | **612** | **361** | **307** | **843** | **764** | **375** | **620** | **2014** | **2432** |

# APPENDIX C

Total Number of Carabid Beetles
Collected in Each Crop Type
and Tillage Treatment, 1999

| | CRP | | Fallow | | Pea | | Sunflower | | Spring Wheat | | Yellow Mustard | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Species** | **No Till** | **Till** | **No Till** | **Till** | **No Till** | **Till** | **No Till** | **Till** | **No Till** | **Till** | **No Till** | **Till** |
| *Agonum cupreum* | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 16 | 10 |
| *Agonum placidum* | 1 | 6 | 1 | 0 | 5 | 5 | 1 | 1 | 7 | 4 | 38 | 26 |
| *Amara apricaria* | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| *Amara littoralis* | 26 | 32 | 14 | 15 | 12 | 8 | 5 | 7 | 12 | 20 | 59 | 68 |
| *Amara obesa* | 77 | 56 | 22 | 9 | 20 | 16 | 1 | 3 | 32 | 13 | 7 | 6 |
| *Amara quenseli* | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Amara thoracica* | 10 | 17 | 49 | 13 | 8 | 8 | 2 | 3 | 10 | 6 | 11 | 9 |
| *Anisodactylus sanctaecrucis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Bembidion nitidum* | 0 | 2 | 8 | 12 | 5 | 17 | 16 | 27 | 10 | 20 | 8 | 7 |
| *Bembidion nudipenne* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Bembidion obscurellum* | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 2 | 0 | 2 |
| *Bembidion quadrimaculatum* | 1 | 0 | 0 | 5 | 1 | 5 | 1 | 13 | 5 | 13 | 0 | 12 |
| *Bembidion rapidum* | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 2 | 4 |
| *Bembidion versicolor* | 3 | 7 | 3 | 14 | 6 | 13 | 7 | 22 | 8 | 7 | 11 | 12 |
| *Bradycellus conger* | 5 | 3 | 1 | 2 | 3 | 2 | 2 | 6 | 3 | 4 | 8 | 17 |
| *Calleida viridis* | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Calosoma lepidum* | 41 | 45 | 8 | 10 | 39 | 47 | 14 | 14 | 13 | 20 | 38 | 33 |
| *Calosoma luxatum* | 1 | 6 | 1 | 3 | 1 | 6 | 4 | 1 | 3 | 8 | 6 | 7 |
| *Calosoma obsoletum* | 0 | 4 | 0 | 2 | 3 | 3 | 4 | 0 | 2 | 1 | 5 | 11 |
| *Chlaenius sericeus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| *Cicindela limbalis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Cicindela punctulata* | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Cicindela purpurea* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Cratacanthus dubius* | 13 | 18 | 5 | 3 | 1 | 2 | 0 | 1 | 2 | 3 | 0 | 4 |
| *Cymindis borealis* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Cymindis planipennis* | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Dyschirius globulosus* | 4 | 1 | 5 | 10 | 6 | 4 | 3 | 13 | 12 | 3 | 17 | 21 |
| *Harpalus amputatus* | 16 | 14 | 7 | 9 | 15 | 8 | 5 | 9 | 13 | 23 | 9 | 13 |
| | **CRP** | | **Fallow** | | **Pea** | | **Sunflower** | | **Spring Wheat** | | **Yellow Mustard** | |

| Species | No Till | Till | No Till | Till | No Till | Till | No Till | Till | No Till | Till | No Till | Till |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Harpalus compar* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Harpalus desertus* | 1 | 2 | 1 | 3 | 4 | 0 | 1 | 1 | 0 | 0 | 10 | 6 |
| *Harpalus fuscipalpis* | 176 | 113 | 32 | 43 | 74 | 8 | 4 | 23 | 13 | 21 | 2572 | 1771 |
| *Harpalus opacipennis* | 5 | 6 | 1 | 2 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| *Harpalus paratus* | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| *Harpalus reversus* | 31 | 33 | 119 | 29 | 26 | 29 | 7 | 3 | 26 | 28 | 11 | 12 |
| *Harpalus somnulentus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Harpalus ventralis* | 13 | 11 | 10 | 3 | 1 | 1 | 4 | 4 | 7 | 9 | 23 | 26 |
| *Lebia atriceps* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Lebia solea* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| *Microlestes linearis* | 103 | 164 | 77 | 106 | 113 | 114 | 66 | 139 | 99 | 242 | 44 | 87 |
| *Pasimachus elongatus* | 15 | 30 | 18 | 19 | 24 | 37 | 23 | 18 | 24 | 19 | 13 | 29 |
| *Piosoma setosum* | 4 | 27 | 14 | 28 | 25 | 0 | 9 | 6 | 11 | 13 | 7 | 10 |
| *Poecilus corvus* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 1 | 1 |
| *Poecilus lucublandus* | 3 | 2 | 1 | 3 | 4 | 1 | 2 | 2 | 7 | 9 | 5 | 5 |
| *Poecilus scitulus* | 7 | 6 | 1 | 10 | 11 | 13 | 0 | 2 | 8 | 11 | 9 | 14 |
| *Stenolophus comma* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| *TOTAL* | 559 | 616 | 401 | 354 | 412 | 350 | 183 | 319 | 330 | 503 | 2933 | 2228 |

# APPENDIX D

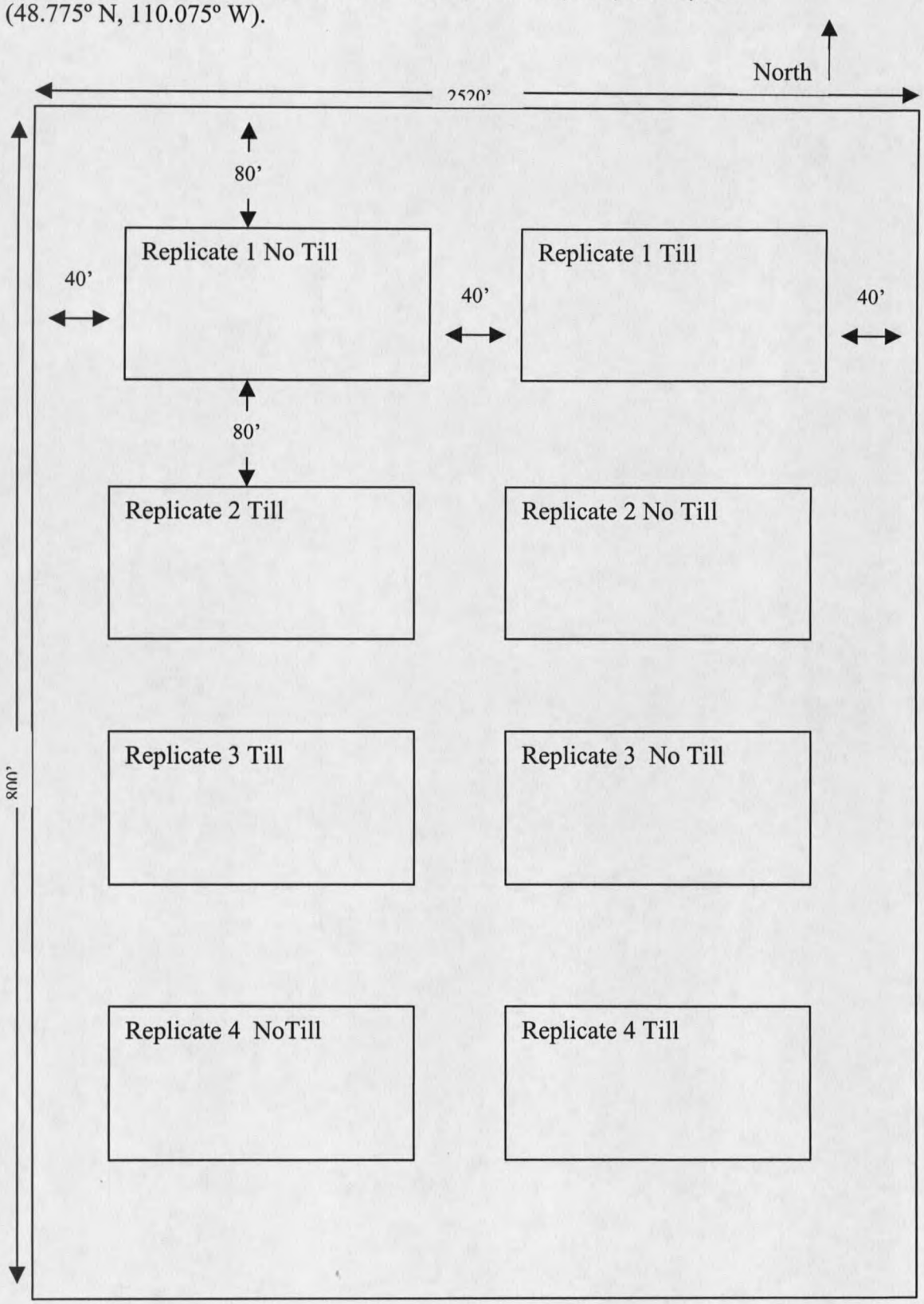
Approximate Phenological Stages of Crops

| | 15-Apr | 1-May | 15-May | 1-Jun | 15-Jun | 1-Jul | 15-Jul | 1-Aug | 15-Aug | 1-Sep |
|---|---|---|---|---|---|---|---|---|---|---|
| Spring Wheat | vegetative - elongation | | | | heading | | early dough - hard kernel | | harvest | |
| Pea | vegetative | | | | reproductive | | harvest | | | |
| Yellow Mustard | vegetative | | | | reproductive | | | harvest | | |
| Sunflower | vegetative | | | | | reproductive | | | | harvest |

# APPENDIX E

Plot Maps of Experimental Site

Plot layout diagram at Mark Peterson Grain and Cattle, Inc., Havre, MT (48.775° N, 110.075° W).



Plot diagram for Replicate 1, No Till. 1998 crops in italics, 1999 crops in bold. Plots with numbers in italics were sampled in 1998, plots with numbers in bold were sampled in 1999, and plots with numbers in both bold and italics were sampled both years.

Replicate 1 – No Till N

| | |
|---|---|
| 125 | **Fallow** - Spring Wheat - *Spring Wheat* |
| 124 | *Fallow* - **Spring Wheat** - Pea |
| 123 | **Fallow** - Spring Wheat- *Pea* |
| 122 | *Pea* - **Spring Wheat** - Sunflower |
| 121 | **Fallow** - Chickpea - *Spring Wheat* |
| 120 | *Fallow* - **Spring Wheat** |
| 119 | *Fallow* - **Chickpea** - Spring Wheat |
| 118 | *Fallow* - **Spring Wheat** - Safflower |
| ***117*** | Continuous Spring Wheat |
| 116 | Fallow - *Chickpea* - **Spring Wheat** |
| 115 | Oilseed Demo |
| 114 | Fallow - *Spring Wheat* - **Spring Wheat** |
| ***113*** | **Pea** - Spring Wheat - *Sunflower* |
| **112** | **Fallow** - Yellow Mustard - *Spring Wheat* |
| 111 | *Lentil* - **Spring Wheat** |
| 110 | **Lentil** - *Spring Wheat* |
| 109 | Fallow- *Spring Wheat* - **Pea** |
| *108* | Fallow - *Yellow Mustard* - **Spring Wheat** |
| 107 | **Fallow** - *Spring Wheat* |
| 106 | **Fallow** - Spring Wheat - *Safflower* |
| 105 | *Fallow* - **Spring Wheat** - Spring Wheat |
| ***104*** | *Fallow* - **Yellow Mustard** – Spring Wheat |
| ***103*** | CRP |
| **102** | Pea - *Spring Wheat* - **Sunflower** |
| 101 | *Fallow* - **Spring Wheat** - Safflower |

Plot diagram for Replicate 1, Till. 1998 crops in italics, 1999 crops in bold. Plots with numbers in italics were sampled in 1998, plots with numbers in bold were sampled in 1999, and plots with numbers in both bold and italics were sampled both years.

Replicate 1 – Till N

| | |
|---|---|
| ***150*** | **Pea** – Spring Wheat – *Sunflower* |
| **149** | Pea – *Spring Wheat* - **Sunflower** |
| 148 | *Lentil* – **Spring Wheat** |
| 147 | Oilseed Demo |
| 146 | Fallow- *Chickpea* –**Spring Wheat** |
| 145 | **Fallow** – Chickpea – *Spring Wheat* |
| 144 | *Fallow* – **Chickpea** – Spring Wheat |
| 143 | Fallow – *Spring Wheat* - **Pea** |
| *142* | **Fallow** – Spring Wheat - *Pea* |
| 141 | *Fallow* – **Spring Wheat** – Pea |
| 140 | **Fallow** – Spring Wheat – *Safflower* |
| **139** | **Fallow** – Yellow Mustard – *Spring Wheat* |
| ***138*** | *Fallow* -**Yellow Mustard** – Spring Wheat |
| 137 | Fallow – *Spring Wheat* – **Safflower** |
| *136* | Fallow – *Yellow Mustard* – **Spring Wheat** |
| 135 | *Fallow* – **Spring Wheat** – Safflower |
| 134 | Fallow – *Spring Wheat* – **Spring Wheat** |
| 133 | **Fallow** – Spring Wheat – *Spring Wheat* |
| 132 | *Fallow* – **Spring Wheat** – Spring Wheat |
| 131 | *Pea* – **Spring Wheat** – Sunflower |
| 130 | **Lentil** – *Spring Wheat* |
| 129 | **Fallow** – *Spring Wheat* |
| 128 | *Fallow* – **Spring Wheat** |
| **127** | Continuous Spring Wheat |
| **126** | CRP |

Plot diagram for Replicate 2, Till. 1998 crops in italics, 1999 crops in bold. Plots with numbers in italics were sampled in 1998, plots with numbers in bold were sampled in 1999, and plots with numbers in both bold and italics were sampled both years.

Replicate 2 – Till ← N

| | |
|---|---|
| 225 | Fallow – *Spring Wheat* - **Pea** |
| 224 | Fallow – *Spring Wheat* – **Spring Wheat** |
| 223 | *Fallow* – **Spring Wheat** |
| 222 | Fallow – *Chickpea* – **Spring Wheat** |
| 221 | *Fallow* – **Spring Wheat** – Spring Wheat |
| 220 | **Fallow** – Chickpea - *Spring Wheat* |
| 219 | **Lentil** – *Spring Wheat* |
| 218 | Fallow – *Yellow Mustard* – **Spring Wheat** |
| 217 | Fallow – *Spring Wheat* – **Safflower** |
| 216 | *Lentil* – **Spring Wheat** |
| 215 | *Fallow* – **Chickpea** – Spring Wheat |
| 214 | **Fallow** – Spring Wheat – *Pea* |
| 213 | **Fallow** – *Spring Wheat* |
| ***212*** | **Pea** – Spring Wheat – *Sunflower* |
| ***211*** | Pea – *Spring Wheat* – **Sunflower** |
| ***210*** | *Fallow* – **Yellow Mustard** – Spring Wheat |
| 209 | **Fallow** – Spring Wheat – *Spring Wheat* |
| 208 | *Pea* – **Spring Wheat** – Sunflower |
| 207 | *Fallow* –**Spring Wheat** – Pea |
| 206 | Oilseed Demo |
| 205 | **Fallow** – Spring Wheat – *Safflower* |
| ***204*** | Continuous Spring Wheat |
| 203 | *Fallow* – **Spring Wheat** – Safflower |
| ***202*** | **Fallow** – Yellow Mustard – *Spring Wheat* |
| ***201*** | CRP |

Plot diagram for Replicate 2, No Till. 1998 crops in italics, 1999 crops in bold. Plots with numbers in italics were sampled in 1998, plots with numbers in bold were sampled in 1999, and plots with numbers in both bold and italics were sampled both years.

Replicate 2 – No Till N

| | |
|---|---|
| 250 | Fallow – *Spring Wheat* - **Pea** |
| **249** | Continuous Spring Wheat |
| 248 | *Pea* – **Spring Wheat** – Sunflower |
| **247** | CRP |
| 246 | *Fallow* – **Spring Wheat** – Pea |
| **245** | Pea – *Spring Wheat* – **Sunflower** |
| 244 | Fallow – *Spring Wheat* – **Spring Wheat** |
| **243** | **Fallow** – Yellow Mustard – *Spring Wheat* |
| **242** | **Pea** – Spring Wheat – *Sunflower* |
| ***241*** | *Fallow* – **Yellow Mustard** – Spring Wheat |
| *240* | **Fallow** – Spring Wheat – *Pea* |
| 239 | *Fallow* – **Spring Wheat** |
| 238 | Fallow – *Yellow Mustard* – **Spring Wheat** |
| 237 | **Fallow** – *Spring Wheat* |
| 236 | **Fallow** – Chickpea – *Spring Wheat* |
| 235 | **Fallow** – Spring Wheat – *Safflower* |
| 234 | *Fallow* – **Spring Wheat** – Spring Wheat |
| 233 | **Fallow** – Spring Wheat – *Spring Wheat* |
| 232 | *Fallow* – **Spring Wheat** – Safflower |
| 231 | Fallow – *Chickpea* – **Spring Wheat** |
| 230 | *Fallow* – **Chickpea** – Spring Wheat |
| 229 | *Lentil* – **Spring Wheat** |
| 228 | Oilseed Demo |
| 227 | Fallow – *Spring Wheat* – **Safflower** |
| 226 | **Lentil** – *Spring Wheat* |

Plot diagram for Replicate 3, Till. 1998 crops in italics, 1999 crops in bold. Plots with numbers in italics were sampled in 1998, plots with numbers in bold were sampled in 1999, and plots with numbers in both bold and italics were sampled both years.

Replicate 3 – Till ← N

| | |
|---|---|
| 325 | *Fallow* – **Spring Wheat** - Safflower |
| 324 | **Fallow** – *Spring Wheat* |
| **323** | *Fallow* – **Yellow Mustard** – Spring Wheat |
| **322** | CRP |
| 321 | Fallow – *Spring Wheat* – **Safflower** |
| *320* | Fallow – *Yellow Mustard* - **Spring Wheat** |
| 319 | Oilseed Demo |
| **318** | Continuous Spring Wheat |
| **317** | **Pea** – Spring Wheat – *Sunflower* |
| 316 | *Fallow* – **Spring Wheat** – Pea |
| 315 | *Fallow* – **Spring Wheat** |
| 314 | *Fallow* – **Chickpea** – Spring Wheat |
| 313 | *Fallow* – **Spring Wheat** – Spring Wheat |
| 312 | **Fallow** – Spring Wheat – *Safflower* |
| 311 | Fallow – *Chickpea* – **Spring Wheat** |
| **310** | **Fallow** – Yellow Mustard – *Spring Wheat* |
| 309 | Fallow _ *Spring Wheat* – **Spring Wheat** |
| *308* | **Fallow** – Spring Wheat – *Pea* |
| 307 | **Fallow** – Spring Wheat – *Spring Wheat* |
| 306 | **Lentil** – *Spring Wheat* |
| 305 | **Fallow** – Chickpea – *Spring Wheat* |
| 304 | *Pea* – **Spring Wheat** – Sunflower |
| **303** | Pea – *Spring Wheat* – **Sunflower** |
| 302 | Fallow – *Spring Wheat* – **Pea** |
| 301 | *Lentil* – **Spring Wheat** |

Plot diagram for Replicate 3, No Till. 1998 crops in italics, 1999 crops in bold. Plots with numbers in italics were sampled in 1998, plots with numbers in bold were sampled in 1999, and plots with numbers in both bold and italics were sampled both years.

Replicate 3 – No Till N

| | |
|---|---|
| 350 | **Fallow** – Spring Wheat - *Safflower* |
| 349 | Fallow – *Spring Wheat* – **Spring Wheat** |
| ***348*** | **Pea** – Spring Wheat – *Sunflower* |
| 347 | *Fallow* – **Spring Wheat** – Spring Wheat |
| 346 | Fallow – *Spring Wheat* – **Pea** |
| 345 | *Fallow* – **Chickpea** – Spring Wheat |
| 344 | **Fallow** – Spring Wheat – *Spring Wheat* |
| 343 | *Lentil* – **Spring Wheat** |
| 342 | *Pea* – **Spring Wheat** – Sunflower |
| 341 | *Fallow* – **Spring Wheat** – Pea |
| 340 | **Fallow** – *Spring Wheat* |
| 339 | **Fallow** – Spring Wheat – *Pea* |
| 338 | *Fallow* – **Spring Wheat** – Safflower |
| 337 | **Lentil** – *Spring Wheat* |
| 336 | Fallow – *Yellow Mustard* – **Spring Wheat** |
| 335 | **Fallow** – Chickpea – *Spring Wheat* |
| ***334*** | Continuous Spring Wheat |
| **333** | Pea – *Spring Wheat* – **Sunflower** |
| **332** | CRP |
| 331 | *Fallow* – **Spring Wheat** |
| ***330*** | *Fallow* – **Yellow Mustard** – Spring Wheat |
| 329 | Fallow – *Spring Wheat* – **Safflower** |
| 328 | Oilseed Demo |
| **327** | **Fallow** – Yellow Mustard – *Spring Wheat* |
| 326 | Fallow – *Chickpea* - **Spring Wheat** |

Plot diagram for Replicate 4, No Till. 1998 crops in italics, 1999 crops in bold. Plots with numbers in italics were sampled in 1998, plots with numbers in bold were sampled in 1999, and plots with numbers in both bold and italics were sampled both years.

Replicate 4 – No Till N

| | |
|---|---|
| 425 | *Pea* – **Spring Wheat** - Sunflower |
| 424 | Fallow – *Spring Wheat* – **Spring Wheat** |
| 423 | **Fallow** – Spring Wheat – *Safflower* |
| ***422*** | *Fallow* – **Yellow Mustard** – Spring Wheat |
| 421 | Fallow – *Spring Wheat* – **Spring Wheat** |
| 420 | *Lentil* – **Spring Wheat** |
| 419 | *Fallow* – **Spring Wheat** – Pea |
| ***418*** | CRP |
| ***417*** | **Pea** – Spring Wheat – *Sunflower* |
| 416 | Oilseed Demo |
| 415 | *Fallow* – **Chickpea** – Spring Wheat |
| ***414*** | Continuous Spring Wheat |
| ***413*** | **Fallow** – Yellow Mustard – *Spring Wheat* |
| 412 | **Fallow** – Chickpea – *Spring Wheat* |
| 411 | *Fallow* – **Spring Wheat** – Safflower |
| 410 | Fallow – *Chickpea* – **Spring Wheat** |
| ***409*** | Pea – *Spring Wheat* – **Sunflower** |
| 408 | Fallow – *Spring Wheat* – **Pea** |
| 407 | **Lentil** – *Spring Wheat* |
| 406 | Fallow – *Yellow Mustard* – **Spring Wheat** |
| 405 | **Fallow** – Spring Wheat – *Pea* |
| 404 | **Fallow** – *Spring Wheat* |
| 403 | **Fallow** – Spring Wheat – *Spring Wheat* |
| 402 | *Fallow* – **Spring Wheat** |
| 401 | *Fallow* – **Spring Wheat** – Safflower |

Plot diagram for Replicate 4, Till. 1998 crops in italics, 1999 crops in bold. Plots with numbers in italics were sampled in 1998, plots with numbers in bold were sampled in 1999, and plots with numbers in both bold and italics were sampled both years.

Replicate 4 – Till N

| | |
|---|---|
| 450 | **Fallow** – Chickpea – *Spring Wheat* |
| ***449*** | *Fallow* – **Yellow Mustard** – Spring Wheat |
| ***448*** | **Fallow** – Yellow Mustard – *Spring Wheat* |
| 447 | Fallow – *Spring Wheat* – **Spring Wheat** |
| 446 | *Fallow* – **Spring Wheat** – Safflower |
| 445 | **Fallow** – *Spring Wheat* |
| 444 | Oilseed Demo |
| 443 | **Lentil** – *Spring Wheat* |
| 442 | **Fallow** – Spring Wheat – *Spring Wheat* |
| 441 | *Fallow* – **Chickpea** – Spring Wheat |
| 440 | *Fallow* – **Spring Wheat** |
| ***439*** | **Pea** – Spring Wheat – *Sunflower* |
| 438 | **Fallow** – Spring Wheat – *Safflower* |
| ***437*** | Continuous Spring Wheat |
| 436 | Fallow – *Chickpea* – **Spring Wheat** |
| 435 | Fallow – *Spring Wheat* – **Safflower** |
| 434 | *Lentil* – **Spring Wheat** |
| 433 | **Fallow** – Spring Wheat – *Pea* |
| ***432*** | CRP |
| ***431*** | Pea – *Spring Wheat* – **Sunflower** |
| 430 | Fallow – *Yellow Mustard* – **Spring Wheat** |
| 429 | *Pea* – **Spring Wheat** – Sunflower |
| 428 | *Fallow* – **Spring Wheat** – Pea |
| 427 | Fallow – *Spring Wheat* – **Pea** |
| 426 | *Fallow* – **Spring Wheat** – Spring Wheat |

# APPENDIX F

Tables of F and P values For All Data Analyzed

**All carabid species - Repeated Measures ANOVA Results**

| | 1998 | | 1999 | |
|---|---|---|---|---|
| | F value | Pr>F | F value | Pr>F |
| Date | 52.86 | <0.0001 | 8.86 | <0.0001 |
| Date X crop | 21.56 | <0.0001 | 16.79 | <0.0001 |
| Date X tillage | 1.55 | 0.176 | 3.64 | 0.0088 |
| Date X rep | 0.76 | 0.7184 | 0.96 | 0.4899 |

**All carabid species 1998 ANOVA by date**

| | MAY | | JUNE | | EJULY | | LJULY | | AUG | | SEPT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | F value | Pr>F | F value | Pr>F | F value | Pr>F | F value | Pr>F | F value | Pr>F | F value | Pr>F |
| model | 2.64 | 0.0139 | 37.31 | <0.0001 | 35.05 | <0.0001 | 12.41 | <0.0001 | 3.54 | 0.002 | 1.4 | 0.214 |
| crop | 3.94 | 0.0059 | 78.91 | <0.0001 | 73.08 | <0.0001 | 27.11 | <0.0001 | 6.99 | 0.0001 | 2.19 | 0.0773 |
| tillage | 2.8 | 0.1029 | 3.46 | 0.0712 | 5.62 | 0.0232 | 0.26 | 0.6135 | 0.04 | 0.8435 | 1.1 | 0.3007 |
| crop X tillage | 1.3 | 0.286 | 2.48 | 0.0499 | 2.9 | 0.0267 | 0.13 | 0.9836 | 0.79 | 0.5672 | 0.68 | 0.6418 |

**All carabid species 1999 ANOVA by date**

| | MAY | | JUNE | | EJULY | | LJULY | | AUG | |
|---|---|---|---|---|---|---|---|---|---|---|
| | F value | Pr>F | F value | Pr>F | F value | Pr>F | F value | Pr>F | F value | Pr>F |
| model | 1.87 | 0.0784 | 12.32 | <0.0001 | 10.75 | <0.0001 | 46.04 | <0.0001 | 5.57 | 0.0002 |
| crop | 1.99 | 0.1044 | 26.82 | <0.0001 | 22.47 | <0.0001 | 82.99 | <0.0001 | 12.03 | <0.0001 |
| tillage | 10.28 | 0.0028 | 0.62 | 0.4361 | 2.89 | 0.0977 | 7.58 | 0.0111 | 0.82 | 0.3713 |
| crop X tillage | 0.06 | 0.9971 | 0.17 | 0.9708 | 0.61 | 0.6951 | 9.58 | 0.0002 | 0.3 | 0.8763 |

***Harpalus fuscipalpis*** **- Repeated Measures ANOVA Results**

| | 1998 | | 1999 | |
|---|---|---|---|---|
| | F value | Pr>F | F value | Pr>F |
| **Date** | 32.81 | <0.0001 | 11.65 | <0.0001 |
| **Date X crop** | 23.98 | <0.0001 | 19.05 | <0.0001 |
| **Date X tillage** | 0.56 | 0.727 | 4.64 | 0.002 |
| **Date X rep** | 0.67 | 0.8101 | 0.82 | 0.6261 |

***Harpalus fuscipalpis*** **1998 ANOVA by date**

| | MAY | | JUNE | | EJULY | | LJULY | | AUG | | SEPT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | F value | Pr>F | F value | Pr>F | F value | Pr>F | F value | Pr>F | F value | Pr>F | F value | Pr>F |
| **model** | 1.22 | 0.3077 | 43.5 | <0.0001 | 36.1 | <0.0001 | 16.07 | <0.0001 | 4.48 | 0.0003 | 6.19 | <0.0001 |
| **crop** | 1.16 | 0.3459 | 91.92 | <0.0001 | 76.47 | <0.0001 | 34.92 | <0.0001 | 9.83 | <0.0001 | 13.53 | <0.0001 |
| **tillage** | 0.73 | 0.3994 | 1.46 | 0.235 | 1.79 | 0.1897 | 0.05 | 0.8266 | 0.02 | 0.8998 | 0.08 | 0.7779 |
| **crop X tillage** | 1.38 | 0.2542 | 3.48 | 0.0115 | 2.61 | 0.0412 | 0.42 | 0.8328 | 0.03 | 0.9996 | 0.08 | 0.9942 |

***Harpalus fuscipalpis*** **1999 ANOVA by date**

| | MAY | | JUNE | | EJULY | | LJULY | | AUG | |
|---|---|---|---|---|---|---|---|---|---|---|
| | F value | Pr>F | F value | Pr>F | F value | Pr>F | F value | Pr>F | F value | Pr>F |
| **model** | 0.62 | 0.7967 | 16.65 | <0.0001 | 12.26 | <0.0001 | 50.5 | <0.0001 | 7.67 | <0.0001 |
| **crop** | 0.34 | 0.8834 | 36.63 | <0.0001 | 26.32 | <0.0001 | 89.97 | <0.0001 | 17.01 | <0.0001 |
| **tillage** | 0.21 | 0.6462 | 0 | 0.9545 | 0.02 | 0.8961 | 13.88 | 0.001 | 0.16 | 0.6908 |
| **crop X tillage** | 0.99 | 0.4399 | 0.01 | 1 | 0.65 | 0.6655 | 10.07 | 0.0002 | 0.2 | 0.9381 |

*Amara littoralis* - Repeated Measures ANOVA Results

| | 1998 | | 1999 | |
|---|---|---|---|---|
| | F value | Pr>F | F value | Pr>F |
| Date | 14.28 | <0.0001 | 1.39 | 0.2458 |
| Date X crop | 10.26 | <0.0001 | 2.87 | 0.0009 |
| Date X tillage | 0.19 | 0.9668 | 0.38 | 0.8249 |
| Date X rep | 0.79 | 0.6867 | 1.43 | 0.1669 |

*Amara littoralis* 1998 ANOVA by date

| | MAY | | JUNE | | EJULY | | LJULY | | AUG | | SEPT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | F value | Pr>F | F value | Pr>F | F value | Pr>F | F value | Pr>F | F value | Pr>F | F value | Pr>F |
| model | 0.91 | 0.5416 | 2.81 | 0.0095 | 17.08 | <0.0001 | 5.41 | <0.0001 | 0.88 | 0.5639 | 1.91 | 0.0707 |
| crop | 0.8 | 0.557 | 5.71 | 0.0006 | 36.22 | <0.0001 | 11.83 | <0.0001 | 1.42 | 0.2404 | 3.87 | 0.0066 |
| tillage | 2 | 0.1659 | 0.51 | 0.4806 | 0.63 | 0.4327 | 0 | 0.9724 | 0.01 | 0.9341 | 0.57 | 0.4558 |
| crop X tillage | 0.8 | 0.557 | 0.37 | 0.8627 | 1.22 | 0.3184 | 0.07 | 0.9965 | 0.52 | 0.7577 | 0.23 | 0.9482 |

*Amara littoralis* 1999 ANOVA by date

| | MAY | | JUNE | | EJULY | | LJULY | | AUG | |
|---|---|---|---|---|---|---|---|---|---|---|
| | F value | Pr>F | F value | Pr>F | F value | Pr>F | F value | Pr>F | F value | Pr>F |
| model | 1.49 | 0.1767 | 6.66 | <0.0001 | 4.15 | 0.0006 | 1.33 | 0.2749 | 1.66 | 0.1425 |
| crop | 2.38 | 0.058 | 12.68 | <0.0001 | 8.98 | <0.0001 | 2.45 | 0.0738 | 2.82 | 0.0427 |
| tillage | 0.06 | 0.8142 | 0.96 | 0.3341 | 0.05 | 0.8302 | 0 | 1 | 1.71 | 0.2009 |
| crop X tillage | 0.9 | 0.4935 | 1.79 | 0.1426 | 0.15 | 0.9799 | 0.29 | 0.831 | 0.5 | 0.738 |

*Microlestes linearis* - Repeated Measures ANOVA Results

| | 1998 | | 1999 | |
|---|---|---|---|---|
| | F value | Pr>F | F value | Pr>F |
| Date | 7.76 | <0.0001 | 16.51 | <0.0001 |
| Date X crop | 3.18 | <0.0001 | 1.4 | 0.1632 |
| Date X tillage | 2.2 | 0.0557 | 3.78 | 0.0071 |
| Date X rep | 0.75 | 0.7288 | 1.19 | 0.3063 |

*Microlestes linearis* 1998 ANOVA by date

| | MAY | | JUNE | | EJULY | | LJULY | | AUG | | SEPT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | F value | Pr>F | F value | Pr>F | F value | Pr>F | F value | Pr>F | F value | Pr>F | F value | Pr>F |
| model | 2.43 | 0.0223 | 2.55 | 0.0168 | 1.61 | 0.1363 | 1.36 | 0.2319 | 1.29 | 0.2716 | 6.22 | <0.0001 |
| crop | 1.55 | 0.198 | 3.37 | 0.0135 | 1.39 | 0.2524 | 1.28 | 0.2921 | 2.16 | 0.0809 | 9.53 | <0.0001 |
| tillage | 1.92 | 0.174 | 6.61 | 0.0144 | 3.49 | 0.0698 | 6.75 | 0.0135 | 1.48 | 0.2315 | 2.06 | 0.1596 |
| crop X tillage | 3.4 | 0.0129 | 0.93 | 0.4732 | 1.47 | 0.2247 | 0.37 | 0.8687 | 0.38 | 0.8612 | 3.73 | 0.008 |

*Microlestes linearis* 1999 ANOVA by date

| | MAY | | JUNE | | EJULY | | LJULY | | AUG | |
|---|---|---|---|---|---|---|---|---|---|---|
| | F value | Pr>F | F value | Pr>F | F value | Pr>F | F value | Pr>F | F value | Pr>F |
| model | 3.56 | 0.0019 | 4.28 | 0.0006 | 1.94 | 0.0662 | 3.62 | 0.0067 | 1.57 | 0.1686 |
| crop | 4.07 | 0.0049 | 6.93 | 0.0002 | 1.73 | 0.1525 | 2.75 | 0.0515 | 2.87 | 0.0397 |
| tillage | 11.87 | 0.0015 | 5.59 | 0.0242 | 9.72 | 0.0036 | 14.16 | 0.001 | 0.25 | 0.6191 |
| crop X tillage | 1.38 | 0.2564 | 1.36 | 0.2629 | 0.6 | 0.7025 | 1.27 | 0.3063 | 0.6 | 0.6636 |

| *Amara thoracica* - Repeated Measures ANOVA Results | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1998 | | 1999 | | | | | | | | | |
| | F value | Pr>F | F value | Pr>F | | | | | | | | |
| Date | 24.44 | <0.0001 | 6.64 | 0.0001 | | | | | | | | |
| Date X crop | 2.01 | 0.0046 | 3.21 | 0.0003 | | | | | | | | |
| Date X tillage | 0.1 | 0.9914 | 0.08 | 0.9874 | | | | | | | | |
| Date X rep | 0.86 | 0.6152 | 0.74 | 0.7121 | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| *Amara thoracica* 1998 ANOVA by date | | | | | | | | | | | | |
| | MAY | | JUNE | | EJULY | | LJULY | | AUG | | SEPT | |
| | F value | Pr>F | F value | Pr>F | F value | Pr>F | F value | Pr>F | F value | Pr>F | F value | Pr>F |
| model | 1.09 | 0.3956 | 0.89 | 0.5589 | 0.82 | 0.6227 | 3.71 | 0.0014 | 2.67 | 0.0128 | 0.96 | 0.494 |
| crop | 1.02 | 0.423 | 0.55 | 0.7388 | 0.6 | 0.7002 | 6.89 | 0.0001 | 3.3 | 0.0149 | 1.01 | 0.4257 |
| tillage | 1.85 | 0.1827 | 0.13 | 0.7201 | 0.33 | 0.5673 | 0 | 0.9529 | 0.21 | 0.6483 | 0 | 1 |
| crop X tillage | 1.02 | 0.423 | 1.38 | 0.2539 | 1.13 | 0.3606 | 1.27 | 0.2993 | 2.54 | 0.0452 | 1.11 | 0.3711 |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| *Amara thoracica* 1999 ANOVA by date | | | | | | | | | | | | |
| | MAY | | JUNE | | EJULY | | LJULY | | AUG | | | |
| | F value | Pr>F | F value | Pr>F | F value | Pr>F | F value | Pr>F | F value | Pr>F | | |
| model | 0.55 | 0.8586 | 0.49 | 0.8954 | 0.98 | 0.4834 | 0.34 | 0.9399 | 3.64 | 0.0036 | | |
| crop | 0.8 | 0.557 | 0.67 | 0.6453 | 1.01 | 0.4262 | 0.42 | 0.7907 | 4.24 | 0.0077 | | |
| tillage | 0.67 | 0.4196 | 0.8 | 0.3768 | 0.07 | 0.7883 | 0.05 | 0.8205 | 1.8 | 0.1897 | | |
| crop X tillage | 0.27 | 0.9283 | 0.24 | 0.9396 | 1.13 | 0.3638 | 0.33 | 0.8013 | 3.5 | 0.0185 | | |

| *Harpalus paratus* - Repeated Measures ANOVA Results | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1998 | | | | | | | | | | | |
| | F value | Pr>F | | | | | | | | | | |
| Date | 22.56 | <0.0001 | | | | | | | | | | |
| Date X crop | 18.01 | <0.0001 | | | | | | | | | | |
| Date X tillage | 1.65 | 0.1478 | | | | | | | | | | |
| Date X rep | 1.32 | 0.1904 | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| *Harpalus paratus* 1998 ANOVA by date | | | | | | | | | | | | |
| | MAY | | JUNE | | EJULY | | LJULY | | AUG | | SEPT | |
| | F value | Pr>F | F value | Pr>F | F value | Pr>F | F value | Pr>F | F value | Pr>F | F value | Pr>F |
| model | * | * | * | * | 3 | 0.0062 | 15.23 | <0.0001 | 9.46 | <0.0001 | 1.25 | 0.2943 |
| crop | * | * | * | * | 3 | 0.023 | 31.29 | <0.0001 | 18.9 | <0.0001 | 2.07 | 0.0914 |
| tillage | * | * | * | * | 3 | 0.0918 | 2.77 | 0.1046 | 1.65 | 0.2065 | 0.3 | 0.5896 |
| crop X tillage | * | * | * | * | 3 | 0.023 | 1.66 | 0.1692 | 1.59 | 0.1887 | 0.61 | 0.6947 |