

IMPACT OF COVER CROPPING ON ARTHROPODS IN CORN ON THE WESTERN HIGH
PLAINS

by

HOLLY N. DAVIS

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College of Agriculture

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Approved by:

Co-Major Professor
Lawrent Buschman

Approved by:

Co-Major Professor
Jeff Whitworth

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Abstract

This study evaluated whether using a cover crop with corn would increase the threat from spider mites in western Kansas because cover crops may serve as a winter host. This study also evaluated whether a cover crop could affect corn rootworm and other ground dwelling arthropods in the cornfield.

In the first study, downy brome, *Bromus tectorum* L., was used as the winter cover crop. There were two trials repeated for three years each. Each trial included: two amounts of irrigation, downy brome, and herbicide to control weeds. In the first trial there were no significant differences in corn rootworm, *Diabrotica virgifera* LeConte, damage across treatments, because there were no differences in brome residue across the treatments. In the second trial, corn rootworm damage was significantly more in plots with higher amounts of downy brome residue. There were no differences in numbers of spider mites: Banks grass mites, *Oligonychus pratensis* (Banks) or twospotted spider mites, *Tetranychus urticae* Koch, across treatments. Spider mite populations appeared to be suppressed by the predatory mite *Neoseiulus* spp., which also overwintered in the cover crop. Corn rootworm samples taken from a no-till irrigation experiment were variable among irrigation treatments but indicated a trend for rootworm damage to increase with increasing irrigation.

In the second study, winter wheat, *Triticum aestivum* L., was used as the winter cover crop. There were three trials repeated for three years each. Each trial included two amounts of irrigation and winter wheat and three amounts of herbicide to control weeds. Upon completion of the agronomy trials, the plots were split into two subplots and one was tilled. Pitfall traps were installed to capture ground dwelling arthropods: (Coleoptera: Carabidae), wolf spiders (Araneae: Lycosidae) and crickets (Orthoptera: Gryllidae). Four carabid genera were more common under no-till conditions. One was more common in tilled plots. Five carabid genera were more common in plots with a history of high weed densities. Two carabid genera were more numerous in plots with the history of a cover crop. Crickets were more common under no-till conditions. Wolf spiders were more common in no tillage with a history of a cover crop.

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CHAPTER 1 - Introduction and Literature Review

Introduction

Producers in the semi-arid western high plains face a number of challenges. These include water evaporation, soil erosion, competition from weeds, and damage from insect pests. Water available from rainfall or from irrigation is limited. The use of winter cover crops and reduced or no-tillage practices is increasing and can reduce the loss of soil water.

Soils in the U.S. Corn Belt contained over 12% organic matter at one time. After more than 100 years of intense crop production the average organic matter is now less than 6% (Odell et al. 1984). The addition of cover crops to an agronomic system has been shown to improve the system in a number of ways. These cover crops can improve water infiltration, water retention, soil tilth, and soil carbon and nitrogen content (Currie and Klocke 2005, Mallory et al. 1998, Sainju and Singh 1997, Teasdale 1996, Varco et al. 1999, Yenish et al. 1996). They also reduce soil erosion and water runoff. In addition, the use of a reduced or no-till system benefits growers by reducing production costs and soil compaction along with preserving the vertical structure of the soil profile, moderating soil temperatures, and conserving the soil organic matter (Kladivko 2001). These residues may also reduce soil water evaporation from the root zone (Klocke et al. 2007). The use of a winter cover crop along with reduced or no-tillage should greatly improve soil properties.

It has been determined that approximately 30% of water applied to a crop is lost to evaporation in the semi-arid western high plains (Klocke et al. 1985). If tillage is eliminated, the cover crop and the residue it creates on the soil's surface can reduce soil susceptibility to erosion and evaporation. The residue can cushion the force of falling raindrops that would remove soil particles, increase erosion, and improving water infiltration into the soil (Hartwig and Ammon 2002). When cover crops are continually present, surface water runoff is reduced and the loss of nutrients and pesticides through runoff can be totally eliminated (Hall et al. 1984, Ruttimann 2001). They also provide protection from erosion caused by wind which can blow up to 80.5 kilometers per hour in the Great Plains of the U.S. Several studies have shown that no-till or strip tillage land management results in higher crop yields. Norwood (2000) showed that reduced tillage significantly improved corn productivity and water use efficiency in two of four

years even when limited irrigation practices were used. Corn, sorghum, and winter wheat have a tendency to produce more grain from the same amount of applied water when managed as no-till compared to conventional management (Klocke et al. 2007). Under three plant populations and three levels of limited irrigation, crops managed using strip tillage and no-tillage produced 8.1% and 6.4% greater grain yields respectively, than conventional tillage (Lamm et al. 2008).

Cover crops are also beneficial in weed control. Winter wheat could provide up to a three-fold reduction of weed biomass in the absence of herbicides (Currie and Klocke 2005). While this did not reduce weeds to a commercially acceptable level, it could potentially decrease the amount of herbicide inputs needed to achieve acceptable levels of control.

The addition of a cover crop and the reduction of tillage in agroecosystems have been shown to impact insect, mite, and spider populations (Bell 1972, Carmona and Landis 1999, Gustin 1979, and Hummel et al. 2002). This study examines two aspects of how cover cropping and tillage affect these populations. The first aspect focuses on how the presence of a weedy cover crop impacts arthropod assemblages, especially the spider mite complex (Acari) and the western corn rootworm (Coleoptera: Chrysomelidae). The second aspect of this study was done in plots with a history of a cover crop, herbicide induced weed density histories, and tillage treatments and examined how the resulting residues affect carabid (Coleoptera: Carabidae), wolf spider (Araneae: Lycosidae), and cricket (Orthoptera: Gryllidae) populations. A third study examines the impact of a range of irrigation amounts on western corn root worm populations.

Cover crops and land management may play important roles in many arthropod life cycles. In the case of the western corn rootworm, carabids, wolf spiders and crickets, the residues left on the soil surface from the previous years of cover cropping, reduced tillage, and various densities of weed residues created by different herbicide treatments may have a large impact on how these arthropods interact with the environment. Western corn rootworms have been shown to prefer moist habitats for oviposition (Gustin 1979, Kirk et al. 1968). Residues left from a cover crop could increase soil moisture, thus increasing the suitability of the habitat for rootworm oviposition. Many genera of carabids and several ground dwelling crickets are known to feed on crop and weed seeds during at least some stages of their development (Brust and House 1988, Carmona et al. 1999, Luff 2002). Tillage, cover crop, and herbicide treatments made in previous years may determine the amount and availability of food for these insects. Predatory carabids and wolf spiders have been shown to be more common in treatments where

there were more weeds or ground cover (Carmona and Landis 1999, Hummel et al. 2002). Thus, these predators may find more hosts in situations where there is some level of ground cover and seed resources.

The cover crop may also be used directly by insects. It has been demonstrated that cover crops can be used as an alternative food source (Norris and Kogan 2005). Several studies have shown that, in the absence of corn plants, western corn rootworm larvae, *Diabrotica virgifera* LeConte, are capable of developing to at least the second instar on a number of weedy grasses (Clark and Hibbard 2004, Oyediran et al. 2004, Wilson and Hibbard 2004). Phytophagous mites such as the Banks grass mite, *Oligonychus pratensis* (Banks), and the twospotted spider mite (TSM), *Tetranychus urticae* Koch, are known to feed directly on the cover crop and provide a good food source for beneficial invertebrates such as the predatory mite (Bell 1972, Dick 1987).

Regardless of how a particular arthropod uses an available cover crop or increased ground residue, one thing becomes immediately clear. These interactions are very complex and, in a field setting, it may become difficult to determine what these relationships are and how and when they are taking place.

There were three objectives to this thesis. The first was to determine if there are differences in the density of spider mites and predatory mites developing on corn grown in plots that have different cover and irrigation treatments. The results of this experiment will help determine whether a cover crop such as *Bromus tectorum* L. could provide an effective alternative to current spider mite control methods and reduce the use of miticides by allowing predatory mites to suppress spider mite populations from the beginning of the season.

The second objective was to determine if there are differences in western corn rootworm damage levels for corn grown in plots with different cover and irrigation treatments. So far, research on how corn rootworms respond to cover crops as well as soil water levels has been inconclusive. These results will provide further evidence which can be used to answer these questions.

The third objective of this experiment was to determine the combined effects of: two tillage systems, continuous use of a winter cover crop, and three different weed density histories on populations of carabid beetles (Coleoptera: Chrysomelidae), wolf spiders (Araneae: Lycosidae), and crickets (Orthoptera: Gryllidae). This data will help determine how complex

agroecosystems may be affecting these arthropods. Different management practices such as cover cropping, tillage, and herbicide application result in a wide range of residue types and levels.

Increased understanding of how all of these organisms interact with cover crops, tillage, soil moisture, various weed densities and resulting residues can encourage land management decisions that are the most beneficial from two aspects; increasing and preserving productivity of the land, and creating habitats that will increase beneficial arthropod populations and minimize the impact of pests.

Literature Review

Downy Brome (Bromus tectorum L.) as a Cover Crop

This experiment used a weedy grass, *Bromus tectorum* L. as the winter cover crop. This grass is commonly referred to as “downy brome” or “cheatgrass”. Currently, in the United States it is considered a difficult-to-control weed. This is especially true in winter wheat-fallow rotations where there are a limited number of expensive herbicides that give economic or consistent control of downy brome. Further, these herbicides all have the same mode of action and incidence of resistance to this mode of action has been found (Park et al. 2004 a, Park et al. 2004 b). Downy brome is a self-pollinating winter annual that grows 5 to 60 cm tall and has a fibrous root system that only penetrates about 30 cm deep and has only a few main roots (Hulbert 1955). Like most winter annuals, downy brome has seedlings that germinate anytime between late summer and early spring but typically emerge in the fall (Creech et al. 2007). Anderson (1996) reported that the majority of downy brome emergence takes place between late August and early October but that plants can emerge anywhere from August 15 to December 5. The reason for this wide window is that downy brome emergence is correlated with precipitation and since rainfall in the Great Plains is erratic, downy brome emergence can also be spotty (Anderson 1989). Downy brome can produce large numbers of seeds in a year with good conditions. Seed production can exceed 2.6 billion seeds/ha (Anderson 1989). Individual plants that are grown in high densities are known to typically produce around 25 seeds each while a solitary plant under ideal conditions may produce up to 5,000 seeds (Sheley and Petroff 1999). However, this plant is capable of producing some seed even during years of poor growing conditions

For this experiment downy brome was chosen over the previously used winter wheat for several reasons. Because downy brome has a shallower root system than wheat, it should establish easily and may not draw as much water from deeper soil layers (Upadhyaya et al. 1986). As discussed above, this plant is a self-pollinating winter annual and is known to thrive under a variety of conditions. When adequate water is available downy brome emerges readily in the fall. Unlike winter wheat, this cover crop should not require replanting each year, saving growers the added expenses and time associated with planting an additional crop. Because downy brome grows rapidly and reproduces readily under most conditions it adds large amounts of organic matter to the soil, prevents raindrop erosion, promotes water infiltration, and prevents runoff (Upadhyaya et al. 1986, Stewart and Hull 1989). Downy brome should not be competitive with the corn crop because it matures around the same time that corn is planted in the spring. It is dormant during the summer, and typically does not germinate until after the corn has matured in the fall.

The Western Corn Rootworm (Coleoptera:Chrysomelidae)

The western corn rootworm (WCR), *Diabrotica virgifera virgifera* Le Conte, is the only rootworm that is a major pest to continuous corn production in western Kansas. In the Midwest it is the most serious insect pest of corn grown in consecutive years (Levine and Oloumi-Sadeghi 1991). This pest consistently costs growers more than 1 billion dollars annually in terms of control expenses and yield losses (Metcalf 1986). The adults are about 0.6 centimeters long, yellowish, and have a black stripe around the margins of the wing cover. Adults feed on pollen, silks, and even leaf tissue of corn, hampering pollination and reducing corn yield (Pavuk and Stinner 1994, Spike and Tollefson 1989). However, the most significant damage is caused by the larvae, which feed on the developing root system of the corn plant. These larvae are white and slender, reach a length of about 1.5 centimeters, with a dark brown head and dark plate on the terminal segment. Beginning in late July and continuing through September, oviposition occurs directly into the soil in cornfields. The eggs overwinter in the soil and hatch in May and early June to begin feeding (Onstad et al. 2003). Larvae cause damage by tunneling into corn root systems, pruning roots as they grow. WCR larval feeding decreases the plants ability to harvest light, tolerate moisture stress, absorb nutrients, and impairs plant hormone biosynthesis (Riedell 1990, Sloderbeck and Whitworth 2007). Severe feeding causes the corn plant to

“lodge” or fall over. Godfrey et al. (1993) reported that first and second instar larvae were reducing field corn vegetative biomass by as much as 17.4% and that by the end of the season they had reduced grain yield up to 15% in the first year and 40.7% the second year. Branson et al. (1980) reported grain yield reduction of up to 17% due to larval feeding. In addition, during the period of initial feeding damage, plants growing in full sunlight have shown average reduced photosynthetic rates of 7.9% (Godfrey et al. 1993). More economically important are the yield losses that result from plant lodging. Lodged plants cannot easily be harvested using combines. For growers this means additional expenses in both physiological yield loss, harvest losses, and time loss because it takes longer to harvest.

There are currently several methods used to control WCR populations. A method that has been effective in the past is crop rotation. However, there are several problems with this approach in some geographic areas. First, under irrigation in the western high plains, there are few crops that can be rotated with corn that are as profitable. In the United States the most common crop to rotate with corn is soybean, *Glycine max* (L.) (Miller et al. 2006). WCR's have developed “rotation resistant” variants that are able to thrive in rotations of corn with soybeans by laying eggs in soybeans as well as corn fields. Damage in rotated corn was first noted in 1987 in east central Illinois and in 2002 could be found in most of Illinois and in parts of neighboring states (Levine and Oloumi-Sadeghi 1996, Schroeder et al. 2005).

Another control option is to use seed treatments. There are currently three seed treatments available, but they have not given consistent control of WCR larvae (Sloderbeck and Whitworth 2007). To further compound the problem, WCR's have evolved resistance to several insecticides (Ball and Weekman 1962, Meinke et al. 1998). The overuse of insecticides for corn rootworms has been documented and is a difficult practice to change. Many growers will treat fields with a planting time soil insecticide on a regular basis rather than based upon scouting. Surveys conducted by Grey et al. (1991) suggest growers of continuous corn are using much higher soil insecticide rates than needed, and are treating more often than necessary.

In 2003, The U.S. Environmental Protection Agency (USEPA) approved Monsanto's registration of transgenic *Bacillus thuringiensis* (*Bt*) corn designed for the corn rootworm (Mitchell and Onstad 2005). There are now three corn rootworm events on the market and they can be “stacked” with corn borer events (Sloderbeck and Whitworth 2007). These new hybrids are being widely adopted and should reduce insecticide use for the WCR. However, there is also

some concern about the lack of long-term field studies and the possible negative effects of these *Bt* crops on nontarget species. There may be adverse effects when nontarget species are exposed to high concentrations of *Bt* proteins or tissues from *Bt* crops (Bhatti et al. 2005, Hilbeck et al. 1998, and Losey et al. 1999). The rootworm *Bt* is less effective on more mature western corn rootworm larvae (EPA Scientific Advisory Panel 2002). Oyediran et al. (2005) found that there was significantly higher beetle emergence from plots with rootworm *Bt* grown with grassy weeds than in plots with rootworm *Bt* grown alone. This suggests that the WCR's are developing to the second instar on the roots of the grassy weeds and that by the time they move onto the corn they are large enough to tolerate or avoid the endotoxin in the *Bt* corn roots (Oyediran et al. 2005). Wilson and Hibbard (2004) found that under greenhouse conditions and in the absence of corn plants, western corn rootworm larvae could survive at least 14 days and develop to at least the second instar on 18 of 22 wild grass species studied. Other studies have shown that WCR larvae developed to at least the second instar on 50 of the 60 grasses examined (Clark and Hibbard 2004, Oyediran et al. 2004). Larval development on grassy weeds common to cornfields may have important implications for the development of resistance management strategies. In addition, the ability of rootworms to survive on grassy weeds early in their life cycle suggests that the use of cover crops such as downy brome in corn may have the ability to increase larval rootworm survival and damage levels.

There have been relatively few reports investigating the effects of a cover crop or irrigation levels on the WCR based on larval damage ratings. The majority of corn rootworm research has been conducted in the greenhouse rather than in the field. Several studies have looked at how management systems affect adult WCR's. Shaw et al. (1978) reported little tendency for increased oviposition near weeds in soybeans even though the adult beetles were collected more frequently in the weedier areas. Pavuk and Stinner (1994) reported significantly more WCR adults were collected from corn plots grown with mixed weeds than from corn with broadleaf or grassy weeds alone.

WCR's oviposit directly into the soil but it is difficult to study adult female oviposition behavior, especially in the field, because they spend little time on the ground (Kirk et al 1968). Godfrey et al. (1995) studied overwintering egg survival in several environmental conditions and found that eggs had the highest rate of survival at a deeper depth and with the presence of soil crop residues. This suggested that the presence of crop residue might favor egg survival because

it increases the soil moisture retention, including snow cover in the winter. Inversely, fall tillage may increase the overwintering mortality because it disturbs the soil and exposes previously buried eggs to environmental conditions (Godfrey et al 1995). Kirk et al. (1968) found that, in a greenhouse experiment, females preferred to oviposit near clumps of mature foxtails, *Setaria* spp., or under fallen corn leaves compared to corn stalks. Johnson et al. (1984) reported that, in a field study, foxtail infested plots had significantly fewer corn rootworm larvae and adults in one of three years and had numerically fewer rootworms than the weed free plots in all three years. A later study concluded that foxtail populations had a variable but inconclusive influence on rootworm oviposition (Johnson and Turpin 1985). In small-plot studies they found that in one of three years there were significantly higher numbers of eggs in plots with moderate foxtail populations (40 foxtails/m of row). Additional studies, done on a larger scale where herbicide treatments influenced foxtail populations, indicated that WCR damage ratings did not differ among weed management practices, providing further evidence that foxtail populations did not have a consistent effect on egg densities or larval survival. Chege et al. (2005) reported that larval survivorship was significantly impacted by what host plants were available and how early plants were infested. Aside from corn, larval survivorship was highest in large crabgrass, *Digitaria sanguinalis* L, but larvae survived on all six of the weed species studied. Survivorship was also highest when plants were infested relatively early in the plants life cycles. Strnad and Bergman (1987) demonstrated that corn rootworm larvae prefer newly developed roots to older plant roots. This, plus the results obtained by Clark and Hibbard (2004), Oyediran et al. (2004), and Wilson and Hibbard (2004), suggests that the WCR may be able to feed on the roots of downy brome early in the season before corn plants have developed sufficient root systems to be a larval food source.

There is evidence that moisture levels as well as soil conditions impact WCR oviposition site selection. George and Ortman (1965) showed that adult WCR's oviposited readily onto any moist surface, but that the largest egg masses were found in cracks or grooves. In a greenhouse trial it has been shown that WCR's strongly prefer to oviposit in moist soils with a less distinct preference for cracks in the soil (Kirk et al. 1968). Gustin (1979) conducted field research showing that moisture levels affect WCR oviposition. In one of the two years of this study, female rootworms oviposited significantly more eggs in the high moisture plots. However, when topsoil becomes saturated during the period of WCR egg hatch, larval root damage caused by

feeding, and survival to adulthood were all reduced compared to unsaturated soil (Reidell and Sutter 1995). Corn root development appeared to also be reduced in saturated conditions, suggesting that this is not an advantageous control method.

All of this data suggests that there would be higher WCR oviposition and larval survival, leading to greater larval feeding damage in plots with downy brome present as a cover crop and with higher levels of soil surface water.

Spider Mites (Acari: Tetranychidae)

The Banks grass mite (BGM), *Oligonychus pratensis* (Banks), and the twospotted spider mite (TSM), *Tetranychus urticae* Koch, can be economically important pests in irrigated field corn in this region. The adult mites are approximately 0.15 cm in length and have four pairs of legs. They have four stages of development; a spherical egg, which hatches into a translucent, six-legged larval stage, followed by two eight-legged nymphal stages, leading into the adult stage. All active life stages feed on corn plants (Godfrey et al. 2002). These mites usually overwinter in grasses located in and around cornfields (Holtzer et al. 1984). In the spring and early summer these mites disperse into cornfields, often with the aid of wind currents (Brandenburg and Kennedy 1982, Margolies 1987). Late in the summer, especially under hot, dry conditions, spider mite populations can reach damaging levels where they can reduce corn yield if infestations occur during the tasseling and grain filling stages (Ehler 1974). Mites cause damage to corn by sucking liquid from parenchymal cells of leaves. This leads to premature senescence that causes loss of foliage, stalk breakage, and kernel shrinking (Godfrey et al. 2002). Bacon et al. (1962) showed up to a 47% yield loss with higher incidences of stalk rot and plant lodging when high twospotted spider mite populations remained untreated. Buschman et al. (2004) reported yield losses as high as 8.8 quintals/ha when comparing treated and untreated plots.

The proportion of Banks grass mites to twospotted spider mites seems to decline during the season (Sloderbeck et al. 1988) with Banks grass mites being more common in early summer, (June) while twospotted spider mite populations become more common in August and September. The economic threshold for spider mites occurs when the bottom two leaves of a corn plant are heavily infested with adult female mites, young, and eggs (Archer and Bynum 1990). The problem is that a number of the commonly used miticides act slowly so their effects

may not be seen for up to one week from the time of application (Archer and Bynum 1990). Therefore the treatment decisions need to be made early, before mites have reached economic thresholds, to be effective. In addition, a number of insecticides have been identified that may actually induce Banks grass mite outbreaks (Buschman and DePew 1990). This may be the result of pest resurgence when the spider mite's natural enemies, including predatory mites, are destroyed along with the spider mites.

The spider mite complex is difficult to manage with registered miticides which have performed erratically, especially when applied to control twospotted spider mites (Sloderbeck et al. 1990). Chemical control for the Banks grass mite and the twospotted spider mite in both corn and sorghum is becoming increasingly difficult in the western Great Plains (Yang et al. 2001). This is because the mites rapidly develop resistance to the miticides. Spider mites have a haplo-diploid breeding system where the males are the hemizygous off-spring of the un-mated females (Van Leeuwen et al. 2006). Therefore, the development of resistance-associated mutations is not slowed by recessive genes. This is also magnified by the lack of new miticides available for integration into pest management programs (Bynum et al. 1997, Logan 1983, Mock et al. 1981, Perring et al. 1981, and Ward et al. 1972).

Predatory mites are known to be very effective in controlling spider mite populations (Sloderbeck et al. 1996). In a survey of predatory mites in corn and surrounding vegetation, Messenger et al. (2000) reported that in southwestern Kansas mites from the genus *Neoseiulus* spp. were common and that its population densities were correlated with Banks grass mite populations. Many studies have shown that augmentative releases of predatory mites for spider mite control can lead to various degrees of success in reducing pest densities in a number of perennial crops (Croft and MacRae 1992, Flaherty et al. 1985, Helle and Sabelis 1985, Hoy et al. 1982, McMurtry 1982, Nyrop et al. 1998), some annual row crops, (Osman and Zohdi 1976, Tijerina-Chavez 1991) including field corn (Pickett and Gilstrap 1986, Pickett et al. 1987). However, as Colfer et al. (2004) point out these augmentative releases are most successful in perennial crops that provide less disturbance and abundant overwintering sites as these conditions are the most favorable for population persistence of predator mites. In field crop settings with crops such as corn and cotton, predatory mites often do not control spider mite populations quickly enough to prevent economic damage, or do not provide a high enough level of control to keep spider mite populations below the economic threshold (Colfer et al. 2004).

Picket and Gilstrap (1986) reported that inoculative releases of predatory mites lead to some degree of spider mite control but that it was only significant on one occasion. Levels of suppression also varied across treatments, suggesting the abiotic environment effects predator mite efficacy. In addition, predatory mites are currently expensive to produce commercially and it is not always economically practical for growers to inoculate fields (Sloderbeck et al. 1996).

Spider mites and their predators must have a green-bridge such as downy brome in order to survive the winter (Buschman et al. 1985). They will then move back into cornfields at the beginning of the growing season. Both the twospotted spider mite and the Banks grass mite have been widely documented to use passive aerial dispersal to move from one location to another. This method of dispersal plays a key role in the spider mite's persistence and pest status in agricultural systems (Brandenburg and Kennedy 1982, Margolies and Kennedy 1985, Margolies 1987). As previously documented, the predatory mite *Neoseiulus* sp. is a well-documented predator of the twospotted spider mite and the Banks grass mite on the western Great Plains (Messenger et al. 2000). Like the spider mites, this mite also disperses aerially (Johnson and Croft 1976, 1981). While spider mites only need to migrate to a suitable plant such as corn or sorghum to continue survival, predator mites must migrate to a suitable environment that also has sufficient populations of spider mites to feed on. When predaceous mites disperse passively through the air, they have little control over where they will land. If they land in an unsuitable environment, they will have to aerially disperse again or search by walking for a good location, leading to increased levels of mortality. Jung and Croft (2000) found that overall environmental conditions affected the level of recovery of released predator mites. Soil management practices had a significant effect on how long predatory mites could survive if they landed on the soil and had to continue to search for a suitable environment. Watering along with mulching practices was reported to give the highest recovery of mites by providing shelter and a humid environment. Watering on bare soil resulted in the lowest level of survival. Ambient conditions also played a crucial role in predaceous mite recovery. In warm, humid conditions with dry soil ca. 90% of the released predators were recovered. In contrast, when it was hot and less humid, only ca. 60% of mites were recovered (Jung and Croft 2000).

Currie and Buschman (unpublished data) have shown that spider mites moved rapidly from a winter wheat cover crop into a corn crop and spread throughout the plots so that during June they could be found in all treatments. Predatory mites also moved from the cover crop.

However, they spread at a slower rate than spider mites. They were found only in the cover crop plots until later in the season (July) when they were also recorded in the non-cover crop plots. This shows that with the use of a cover crop predatory mites may have a chance, early in the season, to keep spider mite populations under control.

Additional factors have been shown to effect spider mite populations. These include plant stress, temperature, irrigation and rainfall, and soil moisture levels. Studies have determined an association between Banks grass mite densities and plant stress (Chandler et al. 1979, Kattes and Teetes 1978, and Perring et al. 1982). There are two common hypotheses as to the underlying causes of this relationship. One is that plant compounds that make up crucial mite nutrients become almost optimal for mites as plants age and become stressed (Perring et al. 1983). The second is that conditions causing plant stress change the microenvironment in the crop canopy, making favorable conditions for mite densities to increase (Perring et. al 1984). The combined effects of sufficient host quality and high microenvironmental temperatures account for Banks grass mite population increases during times when plants are under stress (Perring et al.1986). The twospotted spider mite thrives in higher temperatures. Ferro and Chapman (1979) recorded higher percentages of egg hatch at 35° C than at 25 °C. Ho and Lo (1979) reported lower reproductive rates in soybeans at temperatures below 20°C. Higher populations of eggs and mite motiles were produced in rearing chambers kept at 35°C than at 18°C (White and Liburd 2005).

Amounts of irrigation and rainfall and the resulting amounts of soil surface water have also been reported to have an effect on the twospotted spider mite and Banks grass mite. Chandler et al. (1979) concluded that rain or instrument controlled irrigation less than 50cb can limit the severity and continued growth of spider mite populations. He further observed that spider mite densities declined directly after a severe thunderstorm that was accompanied by high winds, dust, and a hard, driving rain. Other studies have reported the same weather related population declines in wheat (Ward 1973) and sorghum (Ehler 1974). In a laboratory, soil kept almost dry and soil with a moderate amount of surface water had significantly more eggs than the high moisture soil that was maintained in a nearly saturated state (White and Liburd 2005). In field trials, under three different amounts of irrigation, it was reported that early in the season the highest mite densities were found in low moisture plots but that there were no differences in mite populations among the soil moistures during the mid-and late season (White and Liburd

2005). In a greenhouse, an overhead irrigation system reduced twospotted and predatory mite populations as much as 68- and 1538-fold, respectively, when compared to drip irrigation (Opit et al. 2006).

Data collected from all of these studies suggest that downy brome should provide an adequate overwintering site for the Banks grass mite, the twospotted spider mite, and predatory mites. While the presence of this green bridge inside of the corn fields may increase the spider mite populations, it may also create a much more suitable habitat for the persistence of predator mite populations compared to corn fields without downy brome. This could lead to increased levels of spider mite control by the predatory mite.

Ground Beetles (Coleoptera: Carabidae)

Carabids (Coleoptera: Carabidae), commonly called ground beetles, are exceedingly common arthropods in annual cropping systems. These beetles spend the majority of their lives on the soil surface or in surface litter and are often considered important biological control agents for both crop insect and weed pests (Clark et al. 2006, Hatten et al. 2007). Many are generalist predators on other invertebrates. A number of species are polyphagous but feed heavily on seed and have been shown to influence weed abundance and species composition through seed predation (Brust and House 1988, Tooley et al. 1999). Due to the important roles that these carabids play there is interest in managing land in a way that maximizes the density and diversity of carabid fauna. It is commonly believed that carabid density and diversity will decline as the magnitude and severity of land management in the form of human disturbance increases. Brust and House (1988) showed that reduction of pesticides, the use of crop rotation, cover crops, manure, and reduced or no-till crop practices promoted higher overall ground beetle abundance.

As previously discussed, it has long been known that the presence of a winter cover crop can have many beneficial effects in an agronomic ecosystem. Cover crops also affect carabid populations and it is important to consider how the addition of cover crops and their resulting residues are altering the environment for these beetles (Carmona and Landis 1999). Cover crops may lead to reduced weed food sources caused by several factors. The disturbance associated with establishing a cover crop reduces weed populations and then competition from a rapidly growing cover crop reduces overall weed biomass and seed production (Currie and Klocke 2005,

Sarrantonio and Gallandt 2003). Also, the resulting residues from the cover crop could decrease weed establishment and the resulting seedling growth (Sarrantonio and Gallandt 2003).

Conversely, some cover crops may provide additional shelter and food for polyphagous carabids as well as the invertebrate prey of predatory carabids.

Numerous studies have used pitfall traps to monitor how cover crops impact carabid populations. Carmona and Landis (1999) reported that captures were consistently more in plots with a cover crop compared to plots without a cover crop. Carabids seem to be more abundant and active in systems with ground cover (Hartwig and Ammon 2002, Hummel et al. 2002). A study contrasting different types of cover crops found that a common seed predator, *Harpalus rufipes* DeGeer, was affected not only by the presence of a cover crop but also by what type of cover it was. *Harpalus rufipes* De Geer was most frequently collected in the vegetated cover crops such as red clover in comparison to treatments that had been recently tilled and planted to a fall cover crop (Gallandt et al. 2005). Cromar et al. (1999) suggested that the type of cover and ground residues might be more important than the amount of residue. They showed that with similar amounts of biomass of three common crop residues, corn, wheat, and soybean seed predation by invertebrates including carabids, was significantly more in corn residue and lowest in wheat residues. They conclude that dense ground cover produced by disked wheat may have reduced invertebrate mobility, suggesting that there is an optimum combination of residue quality and percent ground cover to create the best environment for invertebrates.

Little work has been done on the effects of herbicide applications on carabid populations. Hough-Goldstein et al. (2004) found that with reduced applications of glyphosate there was increased weediness. This increased density of a common carabid, *Harpalus pensylvanicus* De Geer. Where cover crops were killed by mowing or herbicide application, increased numbers of several carabid species were found early in the season where the cover crop was mowed when compared to herbicide killed cover crop (Laub and Luna 1992).

In contrast to herbicide treatments, a great deal of research has gone into the effects of tillage on carabid communities. In a conventional tillage system the physical, chemical, and biological properties of soils are disturbed and this may be detrimental to carabids (Hatten et al. 2007). Many experiments have demonstrated increased densities for ground beetles in no-till systems compared to conventional tillage systems (Anderson 1999, Brust et al. 1985, Holland and Reynolds 2003, and Stinner and House 1990). One group of researchers has shown

decreased densities in no-till plots (Barney and Pass 1986). Still other researchers reported no consistent significant differences between conservation or no-till systems and conventional tillage (Hummel et al. 2002, Huusela-Veistola 1996).

Wolf Spiders (Araneae: Lycosidae)

Wolf spiders (Araneae: Lycosidae) are also considered important in agroecosystems because they are predatory, helping to control pest populations, and because they contribute to the overall biodiversity (Oberg 2007). Like carabids, wolf spider populations have also been known to increase as most types of land management decreases (Schmidt et al. 2005). Spider diversity in general varies from impoverished populations in intensive agriculture to population diversity above what can even be found in natural habitats when agricultural settings are favorable (Nyffeler et al. 1994 and Toft 1989). Cover crops are generally considered beneficial to wolf spiders with individuals being more abundant and more active in cropping systems that had ground cover (Hummel et al. 2002).

Studies looking at the effects of herbicide applications on wolf spiders have shown that herbicides have no apparent direct effect on the spiders and that the resulting amounts of weeds and available ground cover may not have as large an impact on wolf spider populations as it does on carabids. In one year of a three-year study looking at herbicide induced weed levels, wolf spiders showed a response to increased organic matter and dead weed thatch created by herbicide treatments (Hough-Goldstein et al. 2004). In another cover crop and herbicide experiment more wolf spiders were found early in the season where the cover crop was mowed compared to herbicide killed cover crop (Laub and Luna 1992). However, samples taken later in the season showed no significant difference among the treatments.

Tillage also has the potential to affect wolf spider populations. Even if there is no direct response to tillage, other invertebrates may be directly affected by tillage leading to changes in the quantity of food sources for spiders. Strip tillage (tillage is confined to narrow bands where the seed will be planted) had increased numbers of wolf spiders compared to conventional tillage in two of four years (Hummel et al. 2002). Marshall and Rypstra (1999) reported a tendency for there to be more spiders in soybean fields maintained under conservation tillage than conventional tillage but point out that the difference was rarely significant. Other studies have found that wolf spider densities were more in no-till or conservation tillage treatments when

compared to conventionally tilled treatments (House and Parmalee 1985, Paoletti 1987, and Stinner et al. 1988).

Ground Crickets (Orthoptera: Gryllidae)

Ground and field crickets (Orthoptera: Gryllidae) are another group of important seed consumers commonly found in agroecosystems. Several studies have demonstrated that common species of crickets are weed seed predators (Brust and House 1988, Carmona et al. 1999). In a greenhouse, female crickets decreased weed emergence by 15% (White et al. 2007). In the field, during the late summer, crickets were able to consume 70-100% of giant foxtail seeds, *S. faberi*, within corn and soybean treatments (O'Rourke et al. 2006). However, very little research has been done to explore how land management factors may specifically affect cricket populations. Many field studies looking at seed predators in general, collect lower numbers of crickets than other predators such as carabids and therefore do not look very closely at this family. An extensive experiment using pitfall traps reported that of the 28 different orders and families collected, the family Gryllidae comprised an average of only 0.18% of all individuals collected (Cromar et al. 1999). Hough-Goldstein et al. (2004) demonstrated that with decreased herbicide application, plots became weedier and that as seeds increased, cricket populations increased. In a wheat and red clover intercropping system, there was an eight-fold increase in crickets when compared to a wheat monoculture. Higher populations of crickets were linked to a 200% increase in the daily rate of predation on giant foxtail, *Setaria faberi* Herrm, seed (Gallandt et al. 2005).

As has been pointed out by several scientists, there is really no easy way to differentiate between the roles of ground cover, weediness, herbicide use, tillage, ground topography, and substrate characteristics as the main factor effecting ground-dwelling insects, as these factors have always been compounded (Cromar et al. 1999). The objective of this experiment was to determine the combined effects of cover cropping, two tillage systems, and three different rates of herbicide application on the density of the families Carabidae, Lycosidae, and Gryllidae.

CHAPTER 2 - Impact of a Winter Annual Cover Crop on Western Corn Rootworms (Coleoptera: Chrysomelidae) and the Spider Mite Complex (Acari) in Corn Planted after the Cover Crop on the Western High Plains

Abstract

The effect of a winter cover crop, *Bromus tectorum* L., on several economically important pests was studied. This experiment consisted of two trials (north and south); with high and low levels of irrigation, high and low levels of downy brome, and high and low levels of weed control. Corn (*Zea mays* L.) was grown for three consecutive years following the downy brome. Larval western corn rootworm (WCR), *Diabrotica virgifera virgifera* Le Conte, feeding was evaluated the second and third years of corn production. Four to six plants were rated for rootworm feeding using the Iowa State 0-3 damage scale. In the south trial there was no significant difference in damage levels in either year. This appeared to be due to a lack of a significant difference in downy brome residue between high and low treatments by the third growing season. In the north trial, rootworm damage ratings were significantly more in the high than in the low downy brome plots in both years. Residue measurements in the north trial were more in the high downy brome treatments than in the low treatments. These data suggest that increased WCR damage may be associated with cover crops. In 2006, the near surface soil water content was measured on a weekly basis to find a correlation between surface soil water and amounts of rootworm damage in the current or following year. Sub-plots with high irrigation had significantly more surface soil water, but corn rootworm damage levels were not significantly different. In 2006, WCR samples were also taken from a no-till irrigation experiment with six different amounts of irrigation. Damage was variable among the irrigation applications but there was a trend for rootworm damage to increase with increasing irrigation ($R^2=0.42$, $P=0.17$).

The Banks grass mite (BGM), *Oligonychus pratensis* (Banks), the twospotted spider mite (TSM), *Tetranychus urticae* Koch, and predatory mites from the genus *Neoseiulus* spp. were also

monitored. Plant samples were taken three times during the growing season. Samples were placed in Berlese funnels and spider mites and predatory mites collected were examined under the microscope. Both overwintering spider mites and predatory mites were present in downy brome at the beginning of the season. Early season samples demonstrated that the mites moved into the corn, but there were no significant difference between downy brome treatments. In addition, there were no significant differences in spider mite or predatory mite populations between high or low brome treatments in either trial in any year.

Introduction

Corn producers in the semi-arid western high plains face a number of challenges. These include water evaporation, soil erosion, competition from weeds, and damage from insect pests. Water available from rainfall or irrigation is also limited. The use of reduced or no-tillage practices has gained popularity because it can reduce the loss of soil water. The use of winter cover crops may be able to further reduce the loss of soil water.

Soils in the U.S. Corn Belt contained over 12% organic matter at one time, but after more than 100 years of intense crop production the average organic matter is less than 6% (Odell et al. 1984). The addition of cover crops to an agronomic system has been shown to improve the system in a number of ways. Cover crops can improve water infiltration, soil water retention, soil tilth, organic carbon, and nitrogen content (Currie and Klocke, 2005; Mallory et al., 1998; Sainju and Singh, 1997; Teasdale, 1996; Varco et al., 1999; Yenish et al., 1996). Cover crops also reduce soil erosion and water runoff. In addition, the use of a reduced or no-till system benefits growers by reducing production costs and soil compaction along with preserving the vertical structure of the soil profile, moderating soil temperatures, and conserving the soil organic matter (Kladivko 2001). The use of a winter cover crop plus reduced or no-tillage should greatly improve soil properties.

Approximately 30% of water applied to a crop can be lost to soil water evaporation in the semi-arid western high plains (Klocke et al. 1985). If tillage is eliminated, the cover crop and the residue it creates on the surface can reduce soil susceptibility to erosion and evaporation by creating vegetative cover when a crop is not present. The residue can cushion the force of falling raindrops that would remove soil particles, increase erosion, and improve water infiltration (Hartwig and Ammon 2002). When cover crops are continually present, surface water runoff is

reduced and the loss of nutrients and pesticides through runoff can be totally eliminated (Hall et al. 1984, Ruttimann 2001). It also provides protection for erosion from winds of up to 80.5 kilometers per hour, common in the Great Plains of the U.S. Studies by Norwood (2000) showed that reduced tillage significantly improved corn productivity and water use efficiency in two of four years even when limited irrigation practices were used. Corn, sorghum, and winter wheat have the tendency to produce more grain from the same amount of irrigation when managed as no-till compared to conventional management (Klocke et al. 2007). Under three plant populations and three levels of limited irrigation, corn crops managed using strip tillage and no-tillage showed 8.1% and 6.4% greater grain yields than conventional tillage (Lamm et al. 2008).

Cover crops are also beneficial in weed management. Winter wheat cover crop may provide up to a three-fold reduction of weed populations in the absence of herbicides (Currie and Klocke 2005). While this did not reduce weeds to a commercially acceptable level, it could potentially decrease the amount of herbicide inputs needed to achieve acceptable levels of control.

The addition of a cover crop and the reduction of tillage in agroecosystems have been shown to impact insect and mite populations. Cover crops also can be used as an alternative food source (Norris and Kogan 2005). In the absence of corn plants, WCR larvae, *Diabrotica virgifera* LeConte, are capable of developing to at least the second instar on a number of weedy grasses (Clark and Hibbard 2004, Oyediran et al. 2004, Wilson and Hibbard 2004). Phytophagous mites such as the Banks grass mite, *Oligonychus pratensis* (Banks), and the twospotted spider mite (TSM), *Tetranychus urticae* Koch, can utilize the cover crop to survive the winter and they can provide a good food source for beneficial arthropods such as the predatory mite (Bell 1972, Dick 1987).

The Western Corn Rootworm

WCR's are a major pest to continuous corn production in the Midwest of North America and in western Kansas (Levine and Oloumi-Sadeghi 1991). Corn rootworm adults feed on corn pollen, silks, and even leaf tissue, sometimes hampering pollination and thus reducing corn yield (Spike and Tollefson 1989, Pavuk and Stinner 1994). However, the most significant damage to corn is caused by the larvae, which feed on the developing corn root system. Oviposition occurs

directly in the soil in cornfields from late July through September. The eggs overwinter in the soil and larvae hatch in May to early June to begin feeding on seedling corn roots (Onstad et al. 2003). Larvae cause damage by tunneling into corn roots, pruning them as they grow. Rootworm feeding decreases the plant's ability to harvest sunlight, tolerate moisture stress, absorb nutrients from the soil, and it impairs plant hormone biosynthesis (Sloderbeck and Whitworth 2007, Riedell 1990). Severe WCR feeding causes corn plants to "lodge" or fall over. Branson et al. (1980) reported grain yield reduction of up to 17% due to physiological damage from larval feeding. More economically important are the yield losses that result from plant lodging. Lodged plants cannot be easily harvested using combines and growers lose corn that cannot be harvested, and time because it takes longer to harvest.

There are currently several methods used to control WCR populations. A method that has been fairly effective in the past is crop rotation. However, with the development of rotation resistant variants this is becoming increasingly ineffective in some regions. (Miller et al. 2006). Another option is to use seed treatments, but these treatments have not given consistent control of rootworm larvae (Sloderbeck and Whitworth 2007). Soil insecticides have been widely used but rootworms have evolved resistance to several insecticides (Ball and Weekman 1962, Meinke et al. 1998). In 2003, transgenic *Bacillus thuringiensis* (*Bt*) corn designed to protect roots from the larvae became commercially available (Mitchell and Onstad 2005). These new hybrids are being widely adopted and they reduce insecticide use. However, there is also some concern about the lack of long-term field studies to evaluate the possible negative effects of these *Bt* crops on nontarget species. There is also evidence that the rootworm *Bt* is less effective on more mature larvae (EPA Scientific Advisory Panel 2002). A study done by Oyediran et al. (2005) found that there was significantly higher beetle emergence from plots with rootworm *Bt* grown with grassy weeds versus plots with rootworm *Bt* grown without weeds.

There has been little research investigating the effects of a cover crop on the WCR. The majority of corn rootworm experiments have been conducted in the greenhouse rather than in the field. Additionally, the results from past experiments have been inconclusive. Kirk et al. (1968) found that, in a greenhouse, females preferred to oviposit near clumps of mature foxtails compared to cornstalks or under fallen corn leaves. Field experiments demonstrated that western corn rootworm egg densities were not consistently affected by various foxtail densities (Johnson et al 1984, Johnson and Turpin 1985).

There is evidence that moisture levels may also play a role in rootworm oviposition site selection. In a greenhouse trial it has been shown that the WCR preferred to oviposit in moist soil (Kirk et al. 1968). Gustin (1979) conducted a field experiment showing that moisture levels affect rootworm oviposition. In one of the two years of his study, female rootworms oviposited significantly more eggs plots with more soil water.

In this experiment the presence and absence of a cover crop and different irrigation levels were tested to determine if these variables played a significant role in corn rootworm larval damage to corn roots. It was hypothesized that there would be more rootworm damage ratings in plots with downy brome cover crop and with higher levels of soil surface water.

The Spider Mite Complex

The Banks grass mite (BGM), *Oligonychus pratensis* (Banks), and the twospotted spider mite (TSM), *Tetranychus urticae* Koch, are economically important pests in irrigated field corn in western Kansas. These mites usually overwinter in winter annual grasses located in and around cornfields (Holtzer et al. 1984). In the spring and early summer these mites disperse into cornfields, often with the aid of wind currents (Brandenburg and Kennedy 1982, Margolies 1987). Late in the summer, especially under hot, dry conditions, spider mite populations can reach damaging levels where they can affect corn yield if infestations occur during the tasseling and grain filling stages (Ehler 1974). Bacon et al. (1962) conducted studies that showed up to a 47% yield loss, and higher incidences of stalk rot and plant lodging, when high TSM populations remained untreated. Yield losses as high as 8.8 quintals/ha have been reported from plots that were untreated versus those that were sprayed for spider mite control (Buschman et al. 2004).

The spider mite complex is difficult to manage with registered miticides which have performed erratically, especially when applied to control the TSM (Sloderbeck et al. 1990). Most commonly used miticides act slowly so their effects may not be seen for up to one week from the time of application (Archer and Bynum 1990). Therefore, for the most effective control, treatment decisions need to be made early, before mites have reached economic thresholds. In addition, a number of insecticides have been identified that may actually induce BGM outbreaks (Buschman and DePew 1990). This may be the result of pest resurgence when the spider mite's natural enemies, including predatory mites, are destroyed along with the spider mites.

Naturally occurring predatory mites are known to be very effective in controlling spider mite populations (Sloderbeck et al. 1996). For this reason growers are asked to delay treatment for other pests as long as possible to avoid disrupting this natural control in their corn fields. Inoculative releases of predatory mites have also been shown to reduce spider mite populations by as much as 92% (Pickett and Gilstrap 1985). In field settings, artificially introduced predatory mites often do not control spider mite populations quickly enough to prevent economic damage (Messenger et al. 2000). In addition, predatory mites are currently expensive to produce commercially and it is not economically practical for growers to inoculate fields (Sloderbeck et al. 1996). In a survey of predatory mites in corn and surrounding vegetation, Messenger et al. (2000) reported that, in southwestern Kansas, mites from the genus *Neoseiulus* spp. were common and that its population densities correlated with BGM populations.

Spider mites and their predators must have a green-bridge such as downy brome in order to survive the winter (Buschman et al. 1985). They will then move back into cornfields at the beginning of the growing season. Currie and Buschman (unpublished data) have shown that spider mites moved rapidly from a cover crop into a corn crop and spread throughout the plots so that during June they could be found in all treatments. Predatory mites also moved from the cover crop. However, they spread at a slower rate than spider mites. They were found only in the cover crop plots until later in the season (July) when they were also recorded in the non-cover crop plots (Buschman et al. 2004). This shows that, with the use of a cover crop, predatory mites may have a chance, early in the season, to keep spider mite populations under control.

The purpose of this experiment was to determine if a cover crop such as downy brome would have a negative impact by harboring overwintering populations of spider mites, or if the cover crop would have a positive impact because it also harbors overwintering predator mite populations. It was hypothesized that a cover crop could insure that the predator mite populations will be established early in the season and therefore not allow the spider mite populations to flourish.

Methods

Cover Crop Experiment

This experiment was conducted in plots located at the Southwest Research and Extension Center in Garden City, Kansas. They were established by Currie and Klocke to evaluate weed and water management (Currie et al. Manuscript in preparation). This experiment included two complete trials that were started in successive years. The first trial (south) was first planted to corn in 2004, while the second (north) was first planted to corn in 2005. There were 3 experimental factors (eight treatment combinations) and each trial had four replications. There were 2 main plots, which were divided into 4 subplots each for a total of 8 sub-plots in each replication. The agronomic treatments included: 1. two levels of irrigation in the main plots (high or low). 2. two levels of downy brome (high or low) and 3. two levels of weed density (induced by herbicide treatments) (high or low). The main plots were 36.6 meters long and 29.9 meters wide and the subplots were 18.3 m long and 14.9 m wide.

All plots were planted to corn, NK N70-T9 (Yieldgard Bt), using a 6-row planter at 65,000 seeds per hectare. Specific rows within each sub-plot were assigned as yield rows, soil water sampling row, or insect sampling row; therefore, the corn rootworm rows (#4) were planted to a non-Bt corn hybrid, NK N72-J5, to match the maturity of the Bt corn. All rows of this experiment except the insect sampling row were treated with the soil insecticide, Force 3-G, at a rate of 6.25 kg/ha, to control corn rootworm. High and low levels of a pre-emergence herbicide were applied with a 9.14 meter (12 row) tractor-mounted sprayer. The full herbicide rate consisted of 0.04 kg/ha Isoxaflutole, 1.3 at kg/ha atrazine, and 1.8 at kg/ha S-metolachlor. Johnsongrass was unexpectedly detected at the south trial in the first season so the plots were also treated with 0.028 kg ai/ha nicosulfuron in the high herbicide use plots or half that rate in the low herbicide use plots. The plots were managed using no-till practices.

Irrigation was applied using a lateral-move sprinkler system. Each main plot could be irrigated or not irrigated with a modified lateral-move system to achieve the irrigation treatment (Klocke et al., 2003). A uniform irrigation was applied across all plots in fall to insure germination of downy brome and in spring to insure the germination of corn. During the growing season irrigation began when the total available water in the top 1.2 meters of soil in the high

water treatment was depleted 25 to 40%. The high water treatment simulated a medium-capacity 45 L/sec well and consisted of two 25mm irrigations each week. The low-water treatment simulated a lower well capacity of 18 L/sec and consisted of one 25mm irrigation each week.

The four sub-plots were randomly assigned treatment combinations of high or low levels of downy brome cover. The low level of downy brome was produced by applying 0.83 kg/ha glyphosate in early March, before the plants had reached maturity. The high level of downy brome was produced by applying glyphosate in May at late bloom stage. Before the experiment started the area had a naturally established stand of downy brome. Each fall the downy brome germinated from seed produced the previous spring. No additional downy brome was planted during the course of this experiment.

Residue Measurements

Residue measurements were recorded as the percent of each type of residue in 60 observations. The “line transect method” has been used as a non-destructive way of taking residue measurements (Lalflen et al. 1981, Morrison et al. 1993, Richards et al. 1984, and Shelton et al. 1995). This method was modified to measure not only surface cover, but to measure its makeup. Measurements were taken at the beginning of the season at both locations in 2005, 2006, and 2007. A measuring tape was laid on the ground at random angles for a total length of 6.1 meters in each sub-plot. Every 300mm, a residue reading was taken. Ground cover was recorded as: bare ground, brome residue, corn residue, or detritus. This was repeated three times for a total of 18 meters per sub-plot and 60 individual observations. The percentage of the four types of residue was calculated and analyzed to determine if there was a significant difference in the type and level of ground residue for the different treatments.

Sampling for Western Corn Rootworm

To measure WCR damage, corn roots were collected and rated during the second and third years of continuous corn culture. For the south trial this was 2005 and 2006 and for the north trial it was 2006 and 2007. Samples were taken in late June to early July during the period when corn rootworm larvae began pupation. This was when root damage was most severe, but before the plants could begin to regenerate roots, which would make rating damage more difficult. In each sub-plot, plants in the designated row were randomly selected and dug up, making sure to include the crown of the plants. In 2005, four plants were collected from each

sub-plot, while in 2006 and 2007 six plants were collected from each sub-plot. The root masses were thoroughly rinsed and root damage from corn rootworm feeding was rated using the Iowa State 0-3 damage scale (Oleson et al. 2005). During the time when the adult WCR are active (July-late August), the beetles were counted visually on 10 plants in the designated row on a weekly basis.

Measuring Surface Soil Water

In 2006, during the WCR oviposition period, weekly soil samples were taken from all plots in the experiments to determine the gravimetric surface soil water. Samples were taken approximately 48 hours after the high water treatment had been applied to the plots. This was just before the next water application when the sub-plots were in the driest part of the cycle. In each sub-plot four samples were taken from a designated row that had not been used for previous sampling. Each soil plug was 20mm in diameter and was taken to a depth of 50mm. Two of the samples came from the middle of the row and 2 came from approximately 150mm away from the base of a corn plant. These four samples from each sub-plot were combined in a tin can, weighed, and then dried in an oven at approximately 104°C for 48 hours or until samples stopped losing weight. Samples were then weighed again and the dry weight recorded. Soil water was calculated $((\text{wet weight} - \text{dry weight}) / \text{dry weight})$ and the results analyzed to determine if there is a correlation between surface soil water and rootworm damage.

Sampling for Spider and Predator Mites

Spider mite samples were taken three times during each growing season. In 2006 and 2007 the first spider mite sample was collected during late May from the cover crop in order to determine what spider mite populations were overwintering in the downy brome before the corn emerged. This was done by cutting out 0.3 square meter of the downy brome. The second spider mite sample was taken just after the corn plants emerged (V1-V2). Ten whole seedling corn plants were collected from each sub-plot. The third spider mite sample was collected in mid to late July when corn plants were in the early reproductive stages. At this time half of the leaves (one side) were collected from four corn plants from each sub-plot, taking care to collect leaves all the way to the bottom of the plant (Messenger 1998). The samples were processed as described by Messenger et al. (2000). The plant samples were placed in individual paper bags and taken to the lab. Samples were placed in 76-liter Berlese funnels under 100-watt bulbs,

which dried the vegetation, forcing the mites and other arthropods to climb off the leaves and fall into a jar containing 70% methanol. When corn leaves were completely dry, methanol samples were sealed and stored in the laboratory at room temperature until they could be processed. Arthropods were separated from each sample by filtering each sample onto lined, white filter paper in a Buchner funnel. The numbers of mites in each sample were counted using a dissecting microscope and up to 30 mites were mounted on a microscope slide for species identification. The ratio of mites on the slides were used to determine the ratio of BGM and TSM in each plot so that it could be determined if the ratio changed during the growing season.

Irrigation Rate Experiment

Additional corn rootworm data was collected from another agronomic experiment located under the same irrigation system used in the above experiment. This experiment was conducted in plots established by Klocke et al (2003) to evaluate deficit irrigation. Irrigation was applied in six amounts from fully irrigated corn to corn receiving no more than 76mm of annual irrigation. There were four replications of the irrigation treatments. Plots were 28 meters long and 45 meters wide. NK N70-C7 corn was planted on May 4th, 2006, into existing corn stubble. At planting, all rows of this experiment were treated with the soil insecticide, Force 3-G, at a rate of 6.25 kg/ha except row four which was reserved for rootworm sampling. Pre-planting, (March 31), pre-emergence, (May 1) and post-emergence (June 9) applications of glyphosate were applied at a rate of 1.13 kilograms ai/ha. A pre-planting application of dimethylamide salt of 2,4-D was applied at a rate of 1.10 kilograms ai/ha. A pre-emergence application of dimethylamide salt of 2,4-D, (1.10 kilograms ai/ha) atrazine, (1.3 L ai/ha) s-metolachor, (1.23 L ai/ha) and Isoxaflutole (2.5 L ai/ha) were also applied. The plots were managed using no-till practices.

Statistical Evaluation

Most observations taken in 2005, 2006, and 2007 were analyzed as a split-plot 3-factor experiment with 4 replications using an analysis of variance (SAS PROC MIXED) (SAS Institute, 2002). Means were separated using LSD. Each type of ground cover was analyzed separately. Spider mite and predator mite observations recorded in June (before the irrigation and herbicide treatments had been applied) were analyzed using a 2-way analysis of variance

(SAS Institute, 2002). Later observations were analyzed like the rootworm data. Means were separated using LSD.

The corn rootworm observations from the irrigation experiment were analyzed as a two-way analysis of variance with 6 levels of irrigation and 4 replications using an analysis of variance (ANOVA). Means were separated using LSD. A regression analysis was performed to determine the relationship between irrigation and corn rootworm damage levels (SAS institute, 2002).

Results

Residue Measurements

Residue measurements made using “the line transect method” demonstrated that downy brome ground surface coverage was more in the high than in the low brome plots (except the south trial in 2006) and that the percentage of bare ground was more in the low than in the high downy brome plots (Table 2.1). By the second and third years, much of the downy brome residue had disintegrated into detritus so there was more detritus than downy brome residue. Downy brome residue was not influenced by increased inputs such as irrigation levels, and herbicide inputs. There were no significant three-way interactions among downy brome, irrigation, and herbicide treatments. By the third year in each trial the residue left by the current season’s downy brome was less than 1% in the south trial and only 6% in the north trial.

There was less corn residue in the high than in the low downy brome plots in 2005 in the north trial (Table 2.1). More irrigation increased corn residue coverage by 9.8% in the north trial in 2007. In the south trial (2004) the high downy brome treatment depressed corns yield 7.6 quintals/ha (Currie et al. 2008) and this is reflected in the significantly lower corn residue in the high downy brome plots in 2005 (Table 2.1). In the south trial (2005) the three-way interaction between irrigation level, downy brome level, and herbicide level was significant at $P=0.0588$. This interaction suggests that corn residue was unaffected at the level of herbicide treatment under the low irrigation level, but that at high irrigation there was more corn residue in the high herbicide treatments in the low herbicide treatment (Figure 2.1 A and B). However, this trend did not reach statistical significance in the other trial or other years.

Western Corn Rootworm Feeding Damage

In the statistical analysis of the south trial, downy brome, irrigation and herbicide treatment levels did not have significant effects on corn rootworm damage and there were no complex interactions for any of the treatment factors (Table 2.2 and Figure 2.2 A). Rootworm damage increased significantly from an average of under 0.3 to an average of almost 0.9 on the Iowa State 0-3 damage scale between the growing seasons of 2005 and 2006 (Figure 2.2 B). Overall damage ratings were low, and even in the third year of continuous corn, (2006) populations did not reach levels that caused plant lodging. In the south trial, adult populations averaged 1.6 adults per 10 plants. In the north trial they averaged 1.2 adults per 10 plants. So, adult corn rootworm numbers were more in the south trial than the north trial.

In the statistical analysis of the north trial, irrigation and herbicide treatment levels did not have significant effects on corn rootworm damage and there were no complex interactions for any of the treatment factors (Table 2.3). In both 2006 and 2007, the rootworm feeding damage was significantly higher in sub-plots with history of high downy brome levels than plots with a history of low downy brome levels (Figure 2.3 A). Rootworm damage increased significantly from 2006 to 2007, from just over 0.1 to over 0.7 (Figure 2.3 B). As in the south trial, rootworm larval feeding damage was not severe enough to cause yield loss by plant lodging. Visual counts of the adult corn rootworms were lower all three years in the north trial than in the south trial. In 2005, corn rootworm beetle populations averaged only 0.7 adults per 10 plants in 2005, they averaged 0.3 in 2006, and they averaged 0.61 in 2007.

Corn Rootworm Relationship with Surface Soil Water

In the south trial the percent surface moisture analysis of 2006 showed that sub-plots with high irrigation had a significantly higher season long soil surface water than did low irrigation plots (Table 2.4). There was a higher frequency of bare ground in plots with a history of low downy brome than in plots with a history of high downy brome. However, the reciprocal of this is not present for downy brome residue (Table 2.4). Corn rootworm damage ratings taken in 2005 and 2006 are not significantly different for any of the test variables and neither the surface water nor the residue data show any relationship with the corn rootworm damage ratings.

In the north trial, the surface moisture analysis of 2006 indicates that sub-plots with high irrigation had a significantly higher season long soil surface water than did low irrigation plots

(Table 2.5). Corn rootworm damage in 2007 did not show a relationship with the soil surface water during the oviposition period of 2006. However, there was a correlation between downy brome levels and rootworm damage levels. In 2007, an interaction between the soil surface water and downy brome treatments was significant at $P = 0.06$. There was no correlation between rootworm damage and soil surface water, but there was a correlation between downy brome residue and rootworm damage. The analysis of residue measurements shows that in both 2006 and 2007, there are increased amounts of corn residue in sub-plots with more soil surface water (Table 2.5). In both years there was more bare ground in plots with a history of low downy brome and less downy brome residue. In 2007, plots with higher surface moistures had significantly less downy brome residues than plots with less soil surface water. These data suggest that there is a stronger correlation between the history of downy brome and corn rootworm damage than between soil surface water and rootworm damage.

The Spider Mite Complex Populations in the Cover Crop

In all three years of this experiment, both spider mites and predator mites were present in the downy brome in spring and both readily transferred onto the corn plants when they emerged. In corn, the spider mite populations increased during the growing season but did not reach crop-threatening levels in any year. Predator mites were always present together with the spider mites. During the growing seasons of 2006 and 2007, the ratio of BGM and TSM populations started at 96.1 and 98.7% BGM in the downy brome and declined to 86.5 and 69.9% BGM in July (Table 2.6). The TSM populations increased from 3.9 and 1.3% to 13.5 and 30.1% by July.

There were no significant differences in spider mite or predatory mite populations between the high and low brome treatments in the north or south trial in 2005 (Table 2.7 and Figure 2.4 A and B). Both spider mite and predatory mite populations were generally low. In the south trial the downy brome did not survive as well as expected and by 2006 there was no difference in downy brome stands in the plots that were intended to have high and low plant stands. Residue measurements taken at the beginning of the season in 2006 confirm that there was very little downy brome in which mites could overwinter. For this reason the south trial was not sampled for mites in 2006 (Table 2.1).

The north trial had a more consistent downy brome stand to start the trial. This trial was planted one year after the south trial, allowing one additional year for the downy brome seed-

bank to build up in the soil. Residue measurements taken in the north trial showed significantly more downy brome residue and less bare ground in both 2006 and 2007 in the high downy brome treatments (Table 2.1). In 2006, samples taken from downy brome on May 26 had an average 515 spider mites and 154 predator mites per square meter (Figure 2.5 A and B). On June 6 there were no significant differences in mite populations between the high and low downy brome treatments (Table 2.8). The June 6 samples were taken as corn plants began to emerge and showed that mites were already present on the small plants (Figure 2.5 A and B). On July 18 the spider mite population had increased only in the low downy brome plots. The spider mite populations in high brome plots remained steady and predatory mite populations in both downy brome treatments decreased. None of these populations reached damaging levels. There were no significant differences in the mite populations between high and low downy brome treatments (Table 2.8).

In 2007, the May 24 early season downy brome samples had 377 spider mites and 90 predator mites per square meter (Figure 2.6 A and B). These numbers were lower than those for 2006 (Figure 2.5 A and B). There was no significant difference in mite populations in the high and low downy brome treatments (Table 2.9). Samples taken on June 6, when corn was just emerging, indicate that spider mites and predatory mites were already present in the corn (Figure 2.6 A and B). On July 30, spider mite populations had increased but had not reached damaging levels. Predator mite populations increased only slightly.

In each statistical analysis there were no complex interactions for any of the treatment factors. Irrigation and herbicide treatment levels did not have significant effects on predator or spider mite populations.

Western Corn Rootworm Feeding Damage in the Irrigation Experiment

In the irrigation experiment, corn rootworm damage appeared to increase with increasing irrigation but the regression was not very strong, having an R-squared value of only 0.42 and a P value of 0.17. (Figure 2.7). These data support the results found in the cover crop.

Discussion

The Western Corn Rootworm

The agronomic part of this experiment was designed to determine if downy brome could be used as a sustainable cover crop. In the first year of each trial, downy brome populations were robust, producing 6943.8 +/- 1836.4 kg/ha. By the second year downy brome dropped to 1792.0 +/- 336.0 kg/ha and in the third year downy brome was less than 8.25 +/- 6.5 plants per 30.5 meters of row in the south trial, and 7.5 +/- 7.4 plants per 30.5 meters of row in the north trial (Currie and Klocke, manuscript in preparation). Downy brome levels were not affected by irrigation or herbicide inputs because the plants were not living during the time of these applications. The percentage of corn residue was affected by herbicide amounts in one year and by irrigation amounts and the amount of downy brome in two years. More irrigation increased corn yields. In both of those years the high downy brome plots had significantly less corn residue. This could be the result of increased competition with the downy brome plants for water.

In the north trial, WCR's showed a consistent response to more downy brome residue. In both years, larval rootworm feeding damage was more in plots that had high levels of brome. In contrast, the south trial demonstrated no significant differences in corn rootworm damage in any of the treatments. The downy brome stand failed to flourish as expected and by 2006 there was so little downy brome that it was impossible to identify the difference between the downy brome treatments. Low levels of downy brome and therefore lower levels of downy brome residue may very well explain why there was not higher rootworm damage in the high downy brome treatments. Another possibility is that the larval populations were just too small and spotty to detect differences in the damage levels. A number of the root systems that were rated in the south trial showed no feeding damage.

The results of this experiment allow for speculation that the corn rootworms are responding to the downy brome residues. In this study, they were not affected by irrigation. This may be because of the limited range of rates of water application, too small a sample size, or small and spotty corn rootworm infestations. WCR populations were also not affected by weed levels (herbicide application), soil surface water, corn residue, or bare ground. When there

was more downy brome residue present there were increased amounts of rootworm damage. There are several explanations for why WCR damage was more severe in the plots with more downy brome. It is known that rootworms can feed on the roots of grasses when corn roots are not available (Wilson and Hibbard 2004, Clark and Hibbard 2004, Oyediran et al. 2004). Larvae may be feeding on the root systems of the downy brome plants until the corn roots begin to develop, increasing their survival rate over sub-plots without downy brome. Another explanation would be that the females were ovipositing more frequently, or producing more eggs, in plots with more downy brome cover. Past studies have confirmed that there are higher rootworm egg densities in treatments where weedy grasses grown with corn than when corn is grown alone (Kirk et al. 1968).

This would imply that downy brome residue would be preferred over bare ground, or corn residue. Further studies looking at the egg densities in high and low downy brome treatments would need to be completed in order to further support this hypothesis.

The Spider Mite Complex

The BGM were common early in the season. The TSM populations were present and did increase during the season, but did not reach the high levels that are often seen in late August or September. If samples had been taken later in the season (mid-August) when weather was hot and dry, the proportion of twospotted spider mites to Banks grass mites may have increased to a much larger degree.

While this experiment was able to show that both spider mites and predatory mites did overwinter in the downy brome, the presence of the mites in the downy brome did not appear to impact mite populations in the corn plots. This may be due to the fact that mite populations remained too low in all years of this experiment to be able to detect population differences. With larger populations there may have been less variation due to spotty infestations. In both 2005 and 2006, low populations could have been caused, in part, to hailstorms that took place on July 4 of 2005 and July 6 of 2006, causing considerable defoliation on the corn plants, thus destroying the mite's habitat. Heavy storms are known to reduce spider and predatory mite populations (Chandler et al. 1979, Ehler 1974, and Ward 1973).

In addition, the plot size may not have been large enough to effectively show differences in migrating populations. Due to the limitations of available land, plots may have been so close

together that overwintering mites could easily migrate across the plots, entering both high and low downy brome treatments. If this experiment were repeated on a larger scale or with much greater geographical or physical separation of downy brome treatments, greater variances may show up.

Irrigation Experiment

Results from this experiment suggest that corn rootworm damage may increase with higher rates of irrigation. This would support the data from other experiments. However, these results are only suggestive and further replications of this experiment would be needed to verify this hypothesis. In both greenhouse and field experiments, WCR females have produced more eggs into plots with increased levels of soil surface water (George and Ortman 1965, Gustin 1979, and Kirk et al. 1968). However, when moisture becomes too high, there is evidence that rootworm larval survival decreases (Reidell and Sutter 1995).

Figures and Tables

Figure 2.1 Three way interaction for corn residue (A) between irrigation rates and downy brome and (B.) between irrigation rate and herbicide level - south trial 2005.

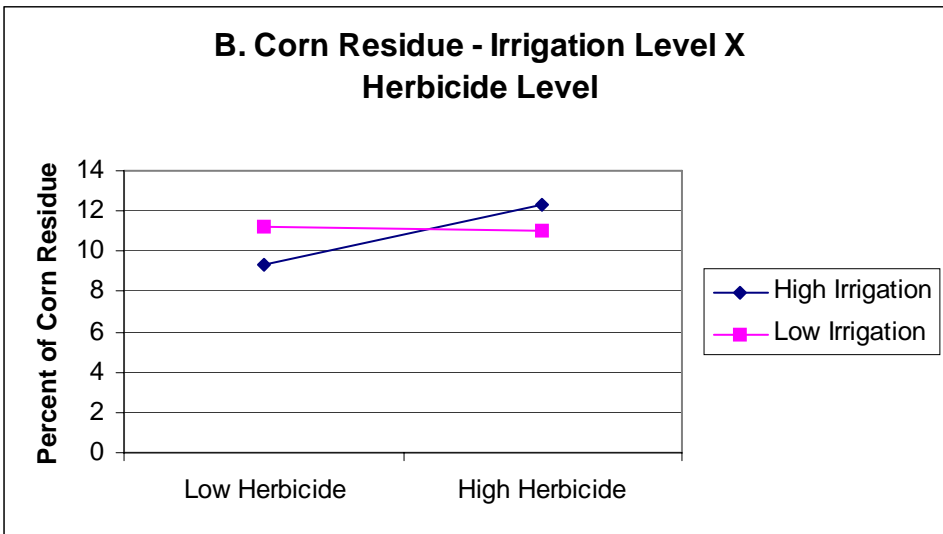
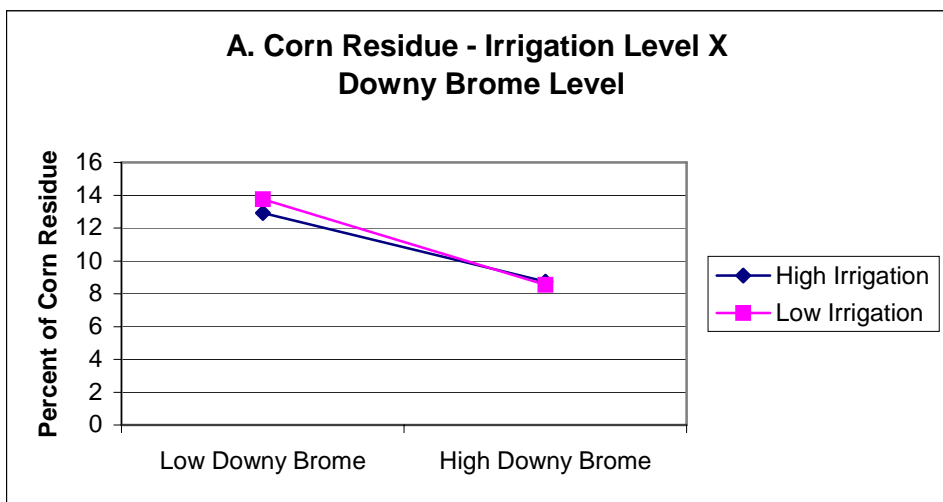


Figure 2.2 Average western corn rootworm (WCR) damage ratings in the south trial, 2005 and 2006. (A.) across downy brome treatments showing individual years, (B.) across years showing differences for downy brome treatments and years.

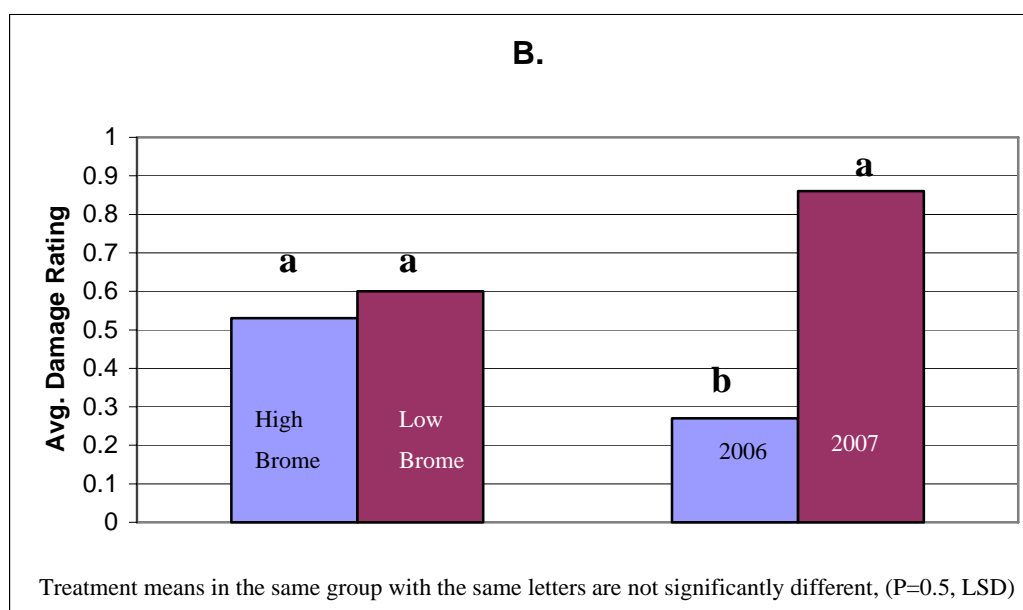
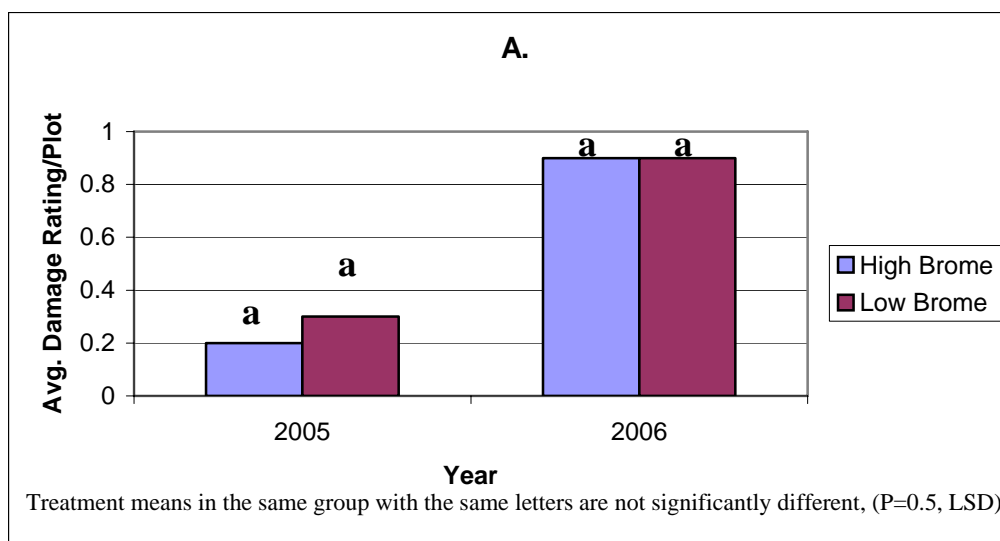


Figure 2.3 Average western corn rootworm (WCR) damage ratings north trial 2006 and 2007. (A.) across downy brome treatments showing individual years, (B.) across years showing differences for downy brome treatments and years.

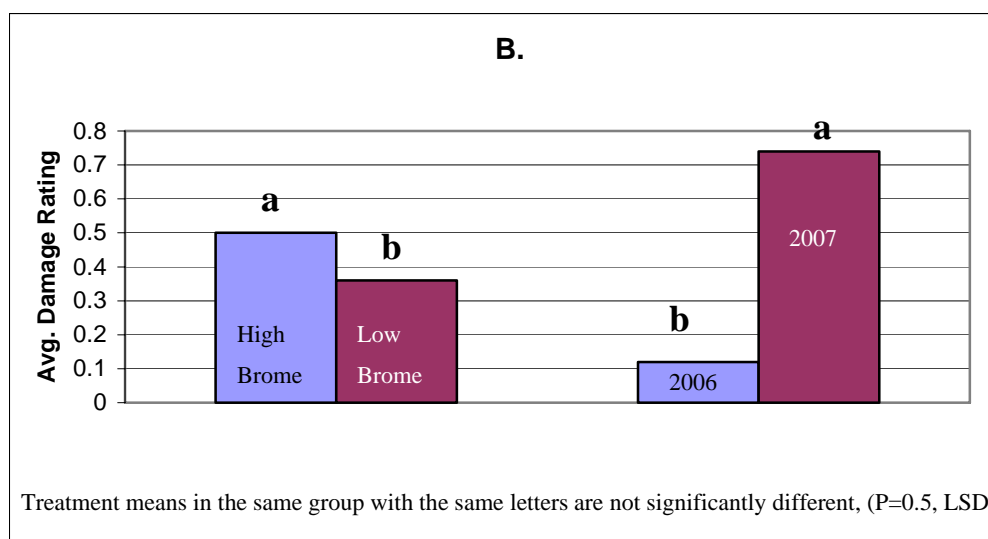
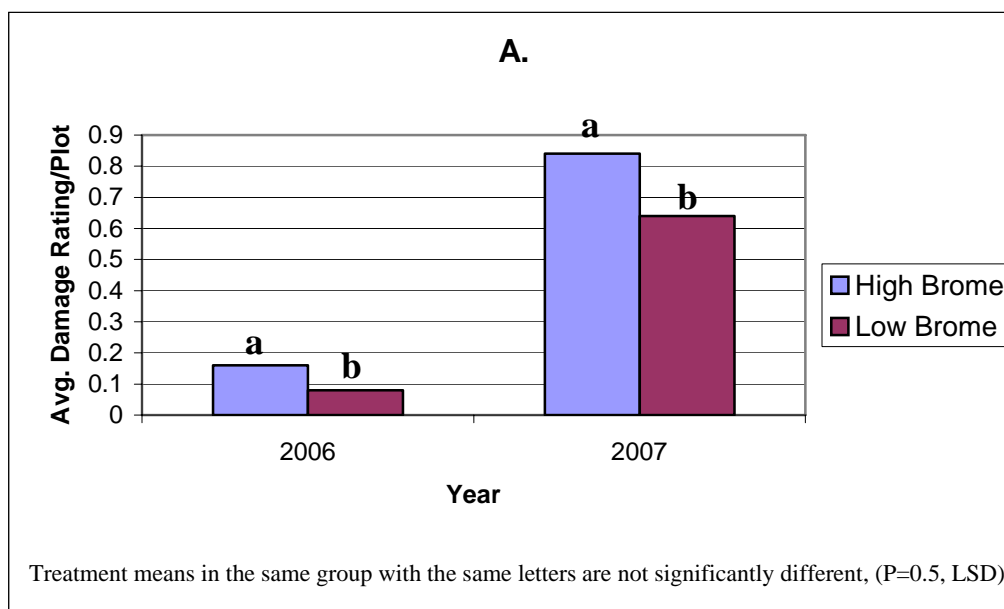


Figure 2.4 Spider mite and predator mite populations from corn June 23, 2005. (A.) south trial and (B.) north trial

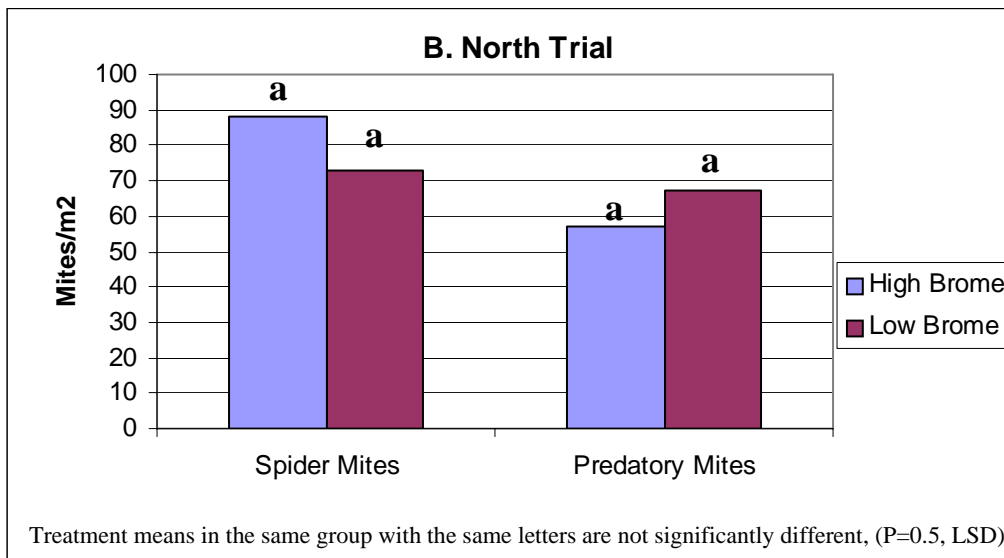
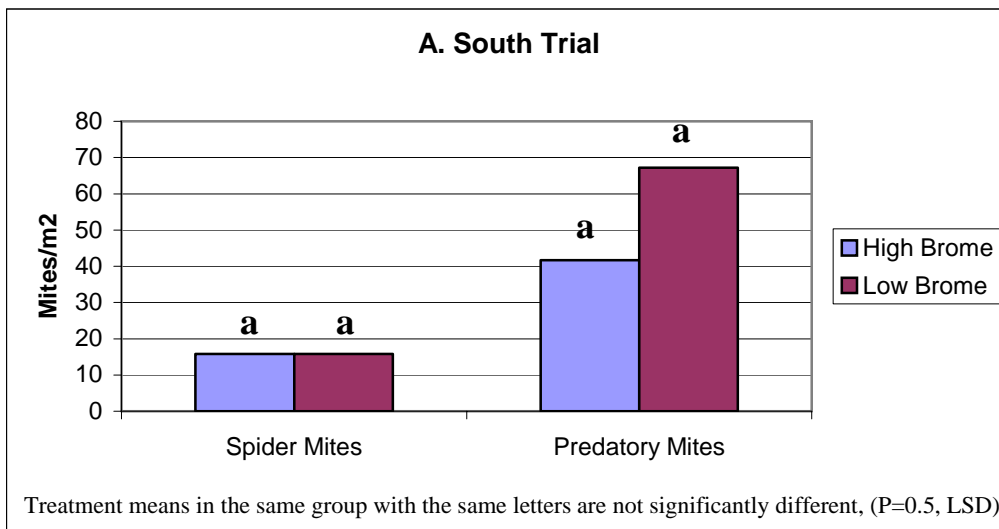


Figure 2.5 Spider mite and predator mite populations from downy brome (May) and corn (June and July), (A.) spider mites and (B.) predator mites – north trial 2006

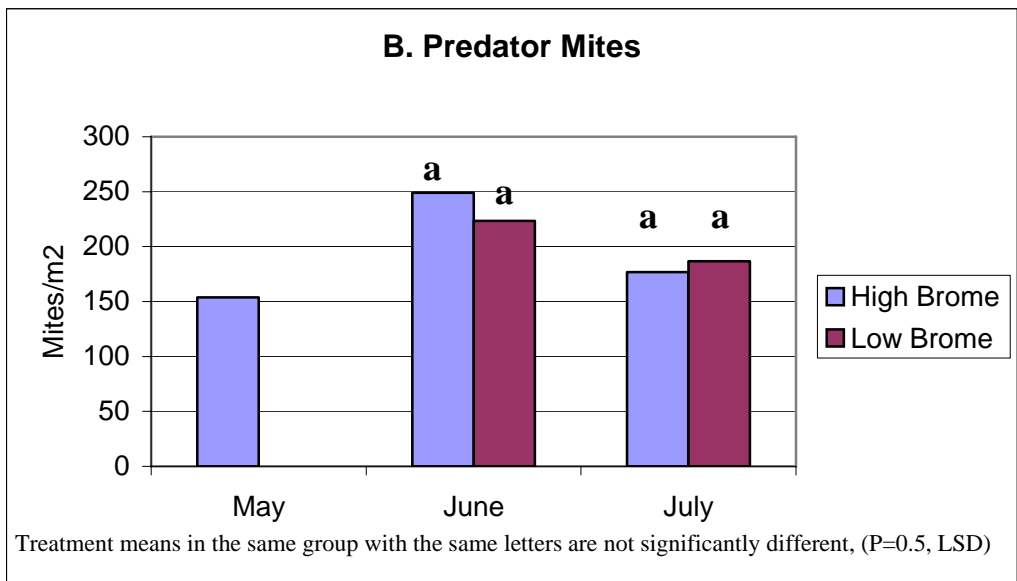
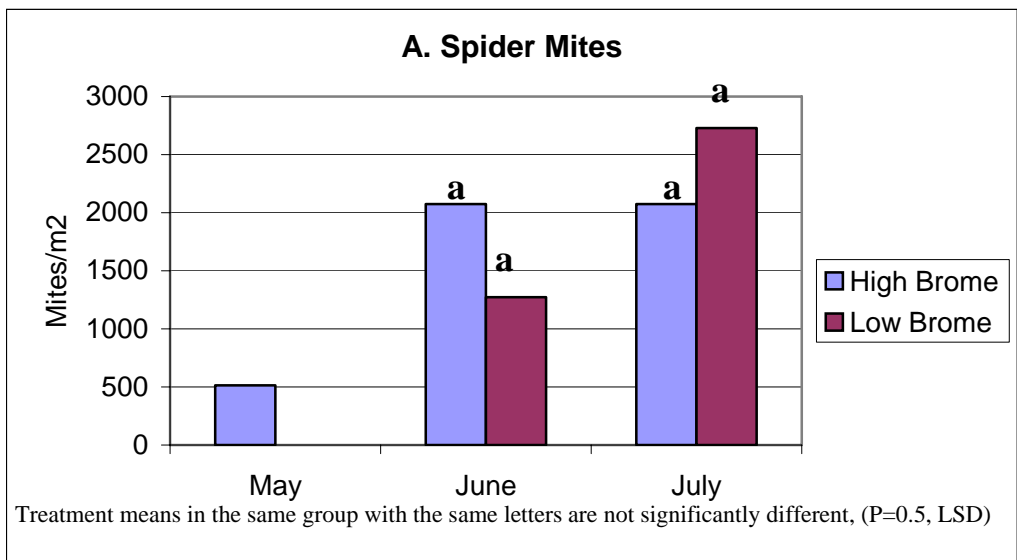


Figure 2.6 Spider mite and predator mite populations from downy brome (May) and corn (June and July), (A.) spider mites and (B.) predator mites - north trial 2007

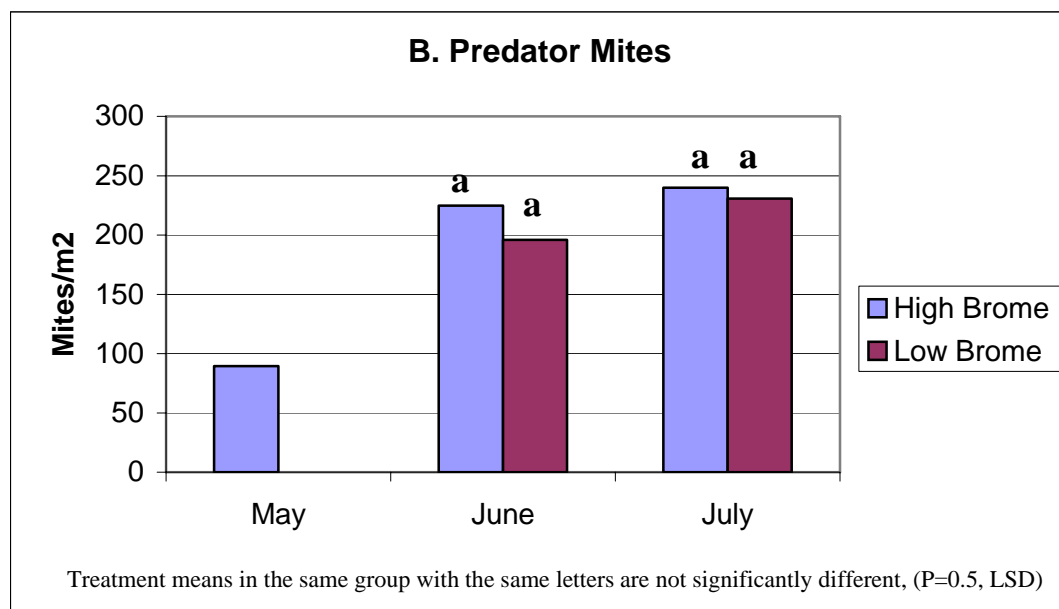
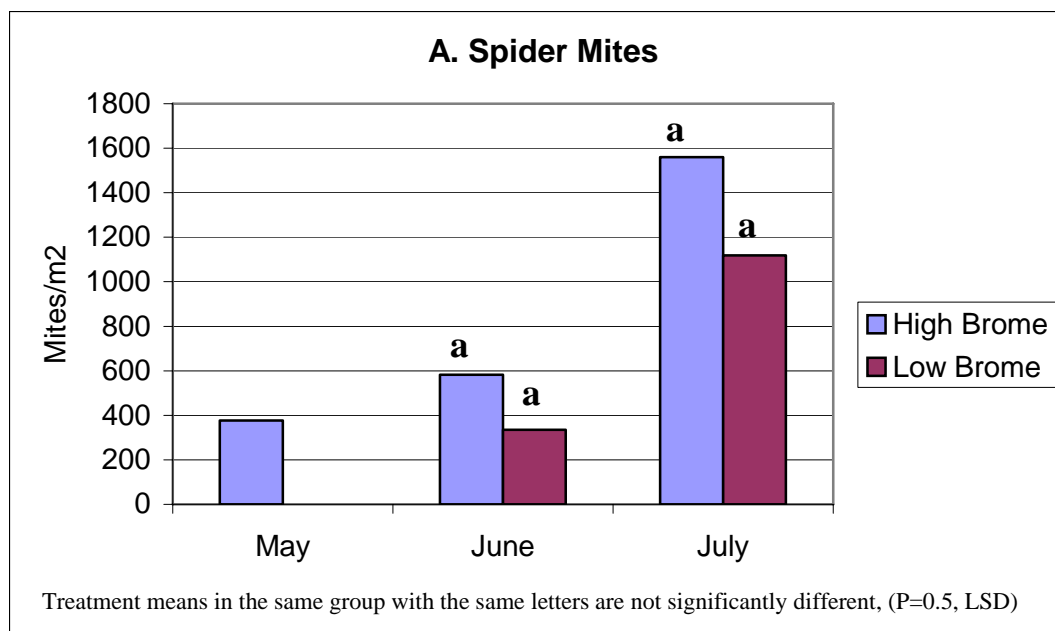


Figure 2.7 Western corn rootworm (WCR) damage ratings in six different irrigation amounts - July 7, 2006. Mean damage ratings among different irrigation levels are not significantly different.

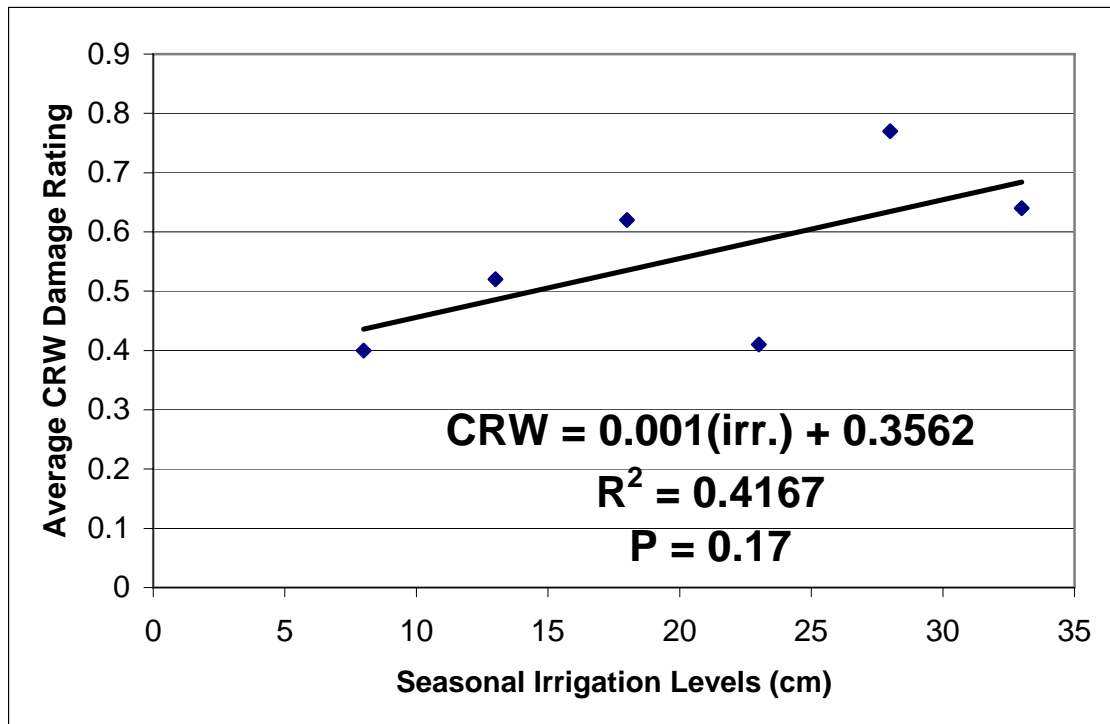


Table 2.1 Residue coverage (%) 2005, 2006 and 2007. Percentage of times each type of residue was recorded in 60 observations. Treatment means in the same group with the same letters are not significantly different, (P=0.5, LSD)

Residue Type	South 2005		South 2006		North 2005		North 2006		North 2007	
	High Brome	Low Brome	High Brome	Low Brome	High Brome	Low Brome	High Brome	Low Brome	High Brome	Low Brome
Bare Ground	16.3 b	34.2 a	30.0 a	35.0 a	6.8 b	46.8 a	36.5 b	56.5 a	24.8 b	41.3 a
Detritus	48.3 a	50.0 a	31.2 a	27.0a	0.4a	0.0 a	30.0 a	29.5 a	19.7 a	9.7 b
Downy Brome	26.8 a	2.5 b	0.6 a	0.2 a	90.2 a	0.0 b	15.6 a	0.0 b	6.0 a	2.2 b
Corn	8.7 b	13.3 a	38.2 a	38.0 a	2.5 b	53.1 a	17.7 a	14.0 a	49.7a	46.8 a

Table 2.2 P-values and means from the ANOVA of western corn rootworm (WCR) larval feeding damage in the south trial, 2005 and 2006. Treatment means in the same group with the same letters are not significantly different, (P=0.5, LSD)

South Trial 2005 and 2006		
	2005	2006
	WCR	WCR
	Damage	Damage
	P-values	P-values
Water	<0.500	<0.500
Downy	0.100	>0.500
Brome		
Herbicide	<0.500	<0.500
Interactions	N.S.	N.S.
Average Damage Rating		
High	0.3 a	0.9 a
Downy		
Brome		
Low Downy	0.3 a	0.9 a
Brome		

Table 2.3 P-values and means from the ANOVA for western corn rootworm (WCR) larval feeding damage in the north trial, 2006 and 2007. Treatment means in the same group with the same letters are not significantly different, (P=0.5, LSD)

North Trial 2006 and 2007		
	2006	2007
	WCR	WCR
	Damage	Damage
	P-values	P-values
Water	>0.500	0.440
Downy	<0.001	0.040
Brome		
Herbicide	0.100	>0.500
Interactions	N.S.	N.S.
Average Damage Rating		
High	0.2 a	0.8 a
Downy		
Brome		
Low Downy	0.1 b	0.6 b
Brome		

Table 2.4 P-values and means from the ANOVA of the surface water content (%), western corn rootworm (WCR) damage ratings and residue surface coverage (%) for the south trial 2005 and 2006. Treatment means in the same group with the same letters are not significantly different, (P=0.5, LSD)

	2006 Surface Soil Water (%)	2005 CRW Rating	2006 CRW Rating	2006 Bare Ground	2006 Downy Brome Residue	2006 Corn Residue
Water	0.003	0.274	0.593	0.317	0.189	0.532
Downy Brome	0.313	0.145	0.922	0.035	0.152	0.950
Water*Brome	0.499	0.331	0.473	0.927	0.750	0.707
Means						
High Water	14.9 a	0.4 a	0.8 a	20.2 a	16.4 a	23.4 a
Low Water	10.0 b	0.2 a	0.9 a	18.8 a	19.0 a	22.2 a
High Downy Brome	12.7 a	0.2 a	0.9 a	18.0 b	19.1 a	22.9 a
Low Downy Brome	12.2 a	0.4 a	0.9 a	21.0 a	16.3 a	22.8 a

Table 2.5 P-values and means from the ANOVA of the surface water content (%), western corn rootworm (WCR) damage ratings and surface coverage (%) in the north trial 2006 and 2007. Treatment means in the same group with the same letters are not significantly different, (P=0.5, LSD)

P-Values	2006 Surface Soil Water (%)	2006 CRW Ratings	2007 CRW Ratings	2006 Bare Ground	2006 Downy Brome Residue	2006 Corn Residue	2007 Bare Ground	2007 Downy Brome Residue	2007 Corn Residue
Water	0.003	0.703	0.507	0.325	0.872	0.080	0.455	0.042	0.015
Downy Brome	0.313	0.003	0.008	0.003	0.025	1.000	<0.0001	0.001	0.476
Water*Brome	0.499	0.68	0.017	0.055	0.391	0.228	0.593	0.507	0.300
Means									
High Water	14.9 a	0.1 a	0.7 a	25.7 a	13.0 a	21.3 a	19.2 a	8.9 b	31.9 a
Low Water	10.0 b	0.1 a	0.8 a	28.8 a	13.7 a	17.4 b	20.5 a	13.5 a	26.0 b
High Downy Brome	12.7 a	0.2 a	0.9 a	22.2 b	18.4 a	19.4 a	14.9 b	15.4 a	29.8 a
Low Downy Brome	12.2 a	0.1 b	0.6 b	32.3 a	8.3 b	19.4 a	24.8 a	7.1 b	21.8 a

Table 2.6 Percentage of Banks grass mite (BGM) and twospotted spider mite (TSM) in samples collected in 2006 and 2007

	2006						2007					
	May-06		June-06		July-06		May-07		June-07		July-07	
	% BGM	%TSM	% BGM	%TSM	% BGM	%TSM	% BGM	%TSM	% BGM	%TSM	% BGM	%TSM
High Downy Brome	96.1	3.9	87.6	12.4	88.3	11.7	98.7	1.3	92.2	6.7	77.6	22.4
Low Downy Brome	-	-	91.2	13	86.5	13.5	-	-	92.5	7.5	69.9	30.1

Table 2.7 P-values and means from the ANOVA for spider mite and predator mite data collected in 2005. Treatment means in the same group with the same letters are not significantly different, (P=0.5, LSD)

	South Trial June 23 2005		North Trial June 29 2005	
	Spider Mites	Predator Mites	Spider Mites	Predator Mites
P-Values				
Water	<0.500	<0.500	<0.500	<0.500
Downy Brome	<0.500	0.200	<0.500	<0.500
Herbicide	<0.500	<0.500	<0.500	<0.500
Interactions	N.S.	N.S.	N.S.	N.S.
Means – Mites / Meter²				
High Downy Brome	15.8 a	41.7 a	88.0 a	57.3 a
Low Downy Brome	15.8 a	67.2 a	73.0 a	67.2 a

Table 2.8 P-values and means from the ANOVA for mid and late season spider mite and predator mite data collected from north 2006. Treatment means in the same group with the same letters are not significantly different, (P=0.5, LSD)

North Trial 2006				
	6-June		18-July	
	Spider Mites	Predator Mites	Spider Mites	Predator Mites
	P-values	P-values	P-values	P-values
Water	-	-	>0.500	>0.500
Downy Brome	0.130	>0.500	0.300	>0.500
Herbicide	-	-	>0.500	>0.500
Interactions	N.S.	N.S.	N.S.	N.S.
Means – Mites / Meter²				
High Downy Brome	2075.0 a	249.0 a	2075.0 a	176.8 a
Low Downy Brome	1270.7 a	223.3 a	2729.0 a	186.8 a

Table 2.9 P-values and means from ANOVA for mid and late season spider mite and predator mite data collected from north 2007. Treatment means in the same group with the same letters are not significantly different, (P=0.5, LSD)

North Trial 2007				
	6-June		30-July	
	Spider Mites	Predator Mites	Spider Mites	Predator Mites
	P-values	P-values	P-values	P-values
Water	-	-	>0.500	0.43
Downy Brome	0.21	>0.500	0.21	>0.500
Herbicide	-	-	>0.500	0.33
Interactions	N.S.	N.S.	N.S.	N.S.
Means – Mites / Meter²				
High Downy Brome	581.8 a	224.9 a	1559.6 a	239.9 a
Low Downy Brome	334.5 a	195.9 a	230.7 a	230.7 a

CHAPTER 3 - Impact of Land Management Practices on Carabids (Coleoptera: Carabidae), Wolf Spiders (Araneae: Lycosidae) and Crickets (Orthoptera: Gryllidae) on the Western High Plains

Abstract

Effects of plant residues created by a history of winter wheat cover crop, history of weed densities caused by herbicide treatments, and tillage treatments on common soil dwelling arthropods including carabids (Coleoptera: Carabidae), wolf spiders (Araneae: Lycosidae) and crickets (Orthoptera: Gryllidae) were evaluated. This work was conducted in agronomic experiments set up to evaluate the effects of a wheat cover crop on weed and water management. The experiments were initiated at three locations within the same large field for three consecutive years. The year following the end of the third growing season, pitfall traps were installed and arthropods were collected and identified. In one location, carabids were identified to the genus level. Ten of the most common genera were statistically analyzed. Four of these genera were more common under no-till conditions. Only one genus was more common in tilled plots. Five genera were more common in plots with a history of high weed densities caused by less herbicide use. The history of decreased weed densities caused by any rate of herbicide use never increased carabid numbers. The past presence of a winter cover crop never reduced carabid numbers, but significantly increased them in two genera. At the first location, crickets were also collected and were found more under no-till conditions. At the other two locations, carabids were identified to family level. Results showed, that in location 2, carabids were more common in plots without the history of a cover crop and in location 3 more carabids were collected when there was tillage. At all locations, wolf spiders were collected and were more common in plots with no tillage and with the past presence of a cover crop. Results suggest that some ground surface residues do impact populations of carabids, wolf spiders, and crickets. More work is needed to further define the impact of these inputs on the individual carabid genera collected in this study.

Introduction

Carabids (Coleoptera: Carabidae), commonly called ground beetles, are very common arthropods in annual cropping systems. These beetles spend the majority of their lives on the soil surface or in surface litter and are often considered important biological control agents for both crop insects and weed pests (Hatten et al. 2007, Clark et al. 2006). They are generalist predators on insect crop pests and some species have been shown to influence weed abundance and weed species composition through seed predation (Brust and House 1988). Due to the important roles that these carabids play, there is interest in managing land in a way that maximizes the density and diversity of carabid fauna. It is commonly believed that carabid density and diversity will decline as the magnitude and severity of land management in the form of human disturbance increases. Research done by Brust and House (1988) showed that reduction of pesticides, the use of crop rotation, cover crops, manure, and reduced or no-till crop practices promoted higher overall ground beetle abundance.

Wolf spiders (Araneae: Lycosidae) are also considered important in agroecosystems because they are predatory on pest populations, and because they contribute to the overall biodiversity (Oberg 2007). Like carabids, wolf spider populations have also been known to generally increase as land management decreases (Schmidt et al. 2005).

Ground and field crickets (Orthoptera: Gryllidae) are important seed consumers commonly found in agroecosystems. Several studies have demonstrated that common species of crickets are weed seed consumers (Brust and House 1988, Carmona et al. 1999). In a greenhouse study, female crickets decreased weed emergence by 15% (White et al. 2007). A field study showed that during the late summer, crickets were able to consume 70-100% of giant foxtail seeds, *S. faberi*, within corn and soybean treatments (O'Rourke et al. 2006). However, very little research has been done to explore how land management factors may affect cricket populations.

It has long been known that the presence of a winter cover crop can have many beneficial effects in an agronomic ecosystem. Cover crops have been shown to reduce soil erosion, water runoff, improve water infiltration, water retention, soil tilth, and organic carbon and nitrogen content (Currie and Klocke 2005, Mallory et al. 1998, Sainju and Singh 1997, Teasdale 1996,

Varco et al. 1999, Yenish et al. 1996). The additional food sources and shelter offered by cover crops may also increase the abundance of ground beetles. Carabid pitfall trap captures were consistently more in plots with a cover crop compared to plots without a cover crop (Carmona and Landis 1999). Hummel et al. (2002) found that both carabids and wolf spiders seemed to be more active in cropping systems that had ground cover, and that ground cover generally increased the abundance of both families.

Little work has been done on the effects of herbicide applications on carabid or wolf spider density or diversity. Hough-Goldstein et al. (2004) found that with reduced applications of glyphosate there was increased weediness. This increased the density of a common carabid, *Harpalus pensylvanicus* De Geer, but had no impact on wolf spiders. Where cover crops were killed by mowing or herbicide application, increased numbers of several carabid species and wolf spiders were found early in the season where the cover crop was mowed when compared to herbicide killed cover crop (Laub and Luna 1992).

In contrast to herbicide treatments, a great deal of research has gone into the effects of tillage on carabid communities. In a conventional tillage system the physical, chemical, and biological properties of soils are disturbed and this may be detrimental to carabids (Hatten et al. 2007). The use of a no-till system benefits growers by reducing production costs and soil compaction. In addition, reducing tillage preserves the vertical structure of the soil profile, moderates soil temperatures, and conserves organic matter (Kladivko 2001). Many experiments have been done that demonstrate increased densities for ground beetles in no-till systems compared to conventional tillage systems (Brust et al. 1985, Stinner and House 1990, Anderson 1999, and Holland and Reynolds 2003). One group of researchers has shown decreased densities in no-till plots and another reported no difference between the two tillage systems (Barney and Pass 1986, Huusela-Veistola 1996). An experiment comparing strip tillage (tillage is confined to narrow bands where the seed will be planted) and conventional tillage found significantly more wolf spiders in plots managed using strip tillage in two of four years. In the other two years, there was no difference between the treatments (Hummel et al. 2002).

The objective of this experiment was to determine the combined effects of a history of cover cropping, a history of weed density caused by different rates of herbicide treatment, and two tillage systems, on the density of carabid beetles, wolf spiders, and crickets. It was hypothesized that carabid, spider, and cricket populations would be higher in plots that had been

managed with no till, had increased weed densities created by no past use of herbicide, and had the history of a winter cover crop. These treatments should have created several levels of crop, weed, and cover crop residues, providing a variable ground cover with multiple food sources for the soil active arthropods.

Methods

This research was conducted in plots established by Currie and Klocke (2005) to look at weed and water management. This experiment consisted of three sites selected from within a 53 ha center pivot irrigated field at the Southwest Research and Extension Center in Garden City, KS. The three locations had been used for non-weed control research for more than 10 years before this experiment began. One year before the arthropod studies were started, the entire area was moldboard plowed to a depth of 450mm and maintained weed free for one summer with 0.83 kg ai ha⁻¹ applications of glyphosate as needed. The three sites, referred to as, locations 1, 2, and 3, were initiated in successive years.

At the first location (location 1), the agronomic treatments began in the fall of 1997 and were repeated using the same unique randomization in 1998, 1999, and 2000. Corn was last planted in May of 2000. The tillage treatment was applied in October 2000 and pitfall trap sampling began at this time and was continued through August, 2001. A concurrent study was conducted in these plots to determine the long-term impact of no-till corn following corn rotation on the decline of the weed seed bank. To prevent weed seed production during this fallow period the entire plot area was sprayed biweekly with 0.83 kg/ha of glyphosate. (Currie 2003, Currie 2004)

At location 2, treatments began in the fall of 1998 and were repeated each fall with the same randomization in 1999, 2000, and 2001. Corn was planted for the last time in May of 2001. The tillage treatment was applied in September, 2001, and pitfall trap sampling began and continued through October, 2002.

At location 3, treatments began in the fall of 1999, and were repeated in 2000, 2001, and 2002. The last corn crop was planted in May, 2002. The tillage treatment was applied in the fall of 2002, and pitfall trap collection began in February, 2003, and continued through September, 2003.

The agronomic experiment was conducted by Currie and Klocke (2005). It included two treatment factors: two amounts of cover ((Currie 2003, Currie 2004) a winter wheat cover crop or no wheat cover crop), and three amounts of weed density caused by three rates of herbicide treatments (high, medium, or no herbicide application).

The cover crop was planted during the first week of October in randomly assigned plots at the respective locations. The winter wheat, 'Tam 107', was drilled in 9m by 14m plots at 100 kg ha⁻¹ in three of the six plots in each of the five replications. When wheat reached the boot stage, around the first week of May, all of the plots were sprayed with 0.83 kg ha⁻¹ of glyphosate to kill the wheat in the cover crop plots and any weeds present in the non-cover crop plots. The herbicide treatment, atrazine, was applied immediately after planting at: 0, 0.8, and 1.6 kg ha⁻¹.

After each of the three-year cover crop agronomic experiments was completed, a second ancillary experiment to measure the long-term impacts of a single tillage event was run concurrently. It was initiated with these plots after the corn was harvested from the previous experiment (To apply the tillage treatment prior to the initiation of the fallow period in a corn-fallow- corn rotation plots were split into two sub-plots (East to West)), and tillage treatments were applied. One sub-plot in each plot was randomly selected to receive the tillage treatment. Conventional tillage treatments were tilled with a tandem disk. This tillage removed an estimated 75% of surface residue based on the residue conservation model (Dickey 1986). Throughout the year, pitfall traps were maintained continuously and were checked at least every two weeks. All plots in all locations were sprayed every two weeks with glyphosate to keep them weed free.

After the tillage treatments had been applied, the pitfall traps were installed in each sub-plot. When the pitfall traps were installed there were no plants in the plots, only the residues left over from the three years of growing corn and weeds and the weed seedlings that emerged between glyphosate applications. Only the tillage treatment was applied during the study period. All other treatments were based upon a three-year cropping history. One pitfall trap was installed in the central part of each sub-plot. These traps consisted of a 13 cm in diameter plastic tube that was inserted into a hole in the ground until the top of the tube was flush with the ground surface (Figure 3.1). Inside each plastic tube a 266-ml plastic drink cup with the bottom cut out served to funnel insects into a smaller plastic cup located in the bottom of the plastic tube. About 2.5 cm of polyethylene glycol automobile antifreeze was added to each trap as a

preservative. A square piece of masonite with three screws placed in it for legs was installed over the pitfall traps with about a 5 cm gap for ground dwelling arthropods to enter the traps (Figure 3.2). The cover served to keep excess dirt, water, and small vertebrates out of the traps. Pitfall traps were monitored every two weeks in the spring and summer and once a month during the late fall and winter. In order to best preserve the insects for identification, traps were also collected any time there was a rain or snow event. After any such event, traps were emptied and new antifreeze added. Insects from the pitfall traps were taken into the lab and identified. Carabids collected from location 1 from 2000 to 2001 were identified to the genus level. Voucher specimens were identified by Wade French at the USDA ARS in Brookings, South Dakota.

Twenty different carabid genera were collected, but only the 10 genera that made up 0.5% or more of the total number of carabids collected were analyzed. The other genera appeared so sporadically and in such low numbers that statistical analysis was not possible. Specimens from location 2 and location 3 were only identified to the family level (Carabidae). Wolf spiders (Lycosidae) were collected at all three locations and identified to the family level. Crickets (Gryllidae) were collected from location 1 and identified to the family level.

Statistical Analysis

The season totals for each insect group were analyzed as a three factorial analysis of variance with two levels of cover crop history (cover and no cover), three levels of weed residue caused by three levels of past herbicide treatments (none, medium, and high), and two levels of tillage (tilled and not tilled) (SAS Institute, 2001). Means were separated by LSD. For location 1, the season total for each genus of Carabidae was analyzed.

Results

Location 1

A total of 7,702 carabid specimens were collected from location 1 in 2000-2001, representing 20 genera (Table 3.1). Although the carabids were not analyzed at the species level, many of the specimens were identified to species. The most common genus was *Amara*, comprising almost 50% of the total specimens collected. The ten most common genera accounted for 98.5% of the total specimens collected. This included *Amara* (*A. impuncticollis* Say, and *A. pennsylvanica* Hayward), *Harpalus* (*H. amputatus* Say and *H. pensylvanicus* De Geer), *Bradycellus* (*B. rupestris* Say), *Stenolophus* (*S. comma* Fabricius and *S. lineola* Fabricius), *Elaphrus* (species not identified), *Scarites* (*S. subterraneus* Fabricius), *Anisodactylus* (*A. carbonarius* Say, and *A. sanctaecrucis* Fabricius), *Poecilus* (*P. chalcites* Say), *Calathus* (*C. opaculus* LeConte), and *Bembidion* (*B. quadrimaculatum* Linnaeus). The less commonly collected genera included *Lebia* (*L. atriventris* Say and *L. solea* Hentz), *Calosoma* (*C. externum* Say), *Cyclotrachelus* (*C. torvus* LeConte), *Pterostichus* (*P. femoralis* Kirby), *Chlaenius* (*C. emarginatus* Say and *C. nemoralis* Say), *Microlestes* (*M. nigrinus* Mannerheim), *Abacidus* (*A. permundus* Say), *Cicindela* (*C. punctulata* Olivier), *Euryderus* (*E. grossus* Say), and *Pasimachus* (*P. elongates* LeConte, 1848). Nomenclature of the carabids was retrieved from the Integrated Taxonomic Information System, ITIS (<http://www.itis.gov>). All of these are common North American carabid genera (Luff 2002, Arnett 1963). At location 1, five of the ten genera showed a significant response to tillage treatments (Table 3.2). In four of these genera (*Amara*, *Anisodactylus*, *Harpalus*, and *Calathus*) no-till sub-plots had significantly more carabids than did tilled sub-plots (Table 3.3). However, in the genus *Stenolophus*, tilled sub-plots had significantly more of this carabid. Five of the ten genera also showed a significant response to herbicide induced changes in the history of weed density (*Amara*, *Bradycellus*, *Scarites*, *Stenolophus*, and *Calathus*) but in only three cases was it the same genera that had a significant response to tillage (Table 3.2). In all five of these genera, plots with a history of high weed densities caused by no atrazine application had more carabids than did lower weed densities (Table 3.3). The presence of a cover crop history had a significant effect on only two genera, *Harpalus*, and *Poecilus* (Table 3.2). In both cases plots with a cover crop history had significantly more carabids (Table

3.3). Statistical analysis showed significant interactions between treatment factors in four genera. In *Amara*, *Calathus* and *Harpalus* there was a two-way interaction between tillage and herbicide induced weed density history (Table 3.2). Figure 3.3 A suggests that in *Amara*, residues left from herbicide induced low weed density history are having some impact but only under no-till situations. *Amara* numbers were more in the no-till than the tilled sub-plots and were the most in low weed density histories. This suggests that atrazine had no negative impacts on this genus. Insect numbers were basically level across the other herbicide induced weed density histories. This also suggests that atrazine had little impact on the species in this genus. Results were very similar for *Calathus* (Figure 3.3 B). In the genus *Harpalus* numbers are level across the high and moderate weed density histories with no-till having consistently more of this carabid (Figure 3.4 A). At low weed density histories, the insect numbers in the no-till sub-plots decreased while numbers in tilled sub-plots increased slightly. For *Harpalus*, there was also a two-way interaction between tillage and cover crop history (Table 3.2). Here the trend was strongest under no-till, and carabid numbers were increased with the residues created by the history of a cover crop (Figure 3.4 B). For the genus *Anisodactylus*, there was a significant interaction between all three-treatment factors (Table 3.2). However, these interactions appear to be more random (Figure 3.5 A and B). The only meaningful trend was there were more *Anisodactylus* in no-till than in tilled plots.

When all of the carabid genera were grouped together into one family for location 1, such as was done at locations 2 and 3, there was a significant difference in carabid numbers for tillage treatments and herbicide-induced weed density histories (Table 3.4). More Carabidae were collected from sub-plots with no tillage and in plots with a high weed density history resulting from no herbicide use. It appears that the history of a cover crop had no effect on carabids. However, it is possible that the changes in the surface residues induced by the higher weed biomass masked the effects of the cover crop history. There were no significant interactions between any of the treatment factors. The history of a cover crop did not have any effect on carabids and there were no significant interactions.

Wolf spiders collected from location 1 were found significantly more in sub-plots managed as no-till and in plots with residues from the history of a cover crop (Table 3.4). There was a two-way interaction between tillage and weed density. Wolf spiders were most common in no-till sub-plots with high weed densities created by the lack of herbicide use (Figure 3.6).

The most wolf spiders were found in no-tillage sub-plots with a history of high weed densities resulting from no herbicide use. Differences between till and no-till decreased under herbicide induced lower weed densities. As was seen for Carabidae, the tillage effect may have been buffered by changes in weed biomass produced by history of atrazine use.

Crickets responded only to tillage treatments (Table 3.4). More of them were collected in no-till sub-plots than in tilled sub-plots. Ground residues created by past cover crops or herbicide induced weed densities did not statistically affect cricket populations. As was seen in *Amara*, *Calathus*, and *Harpalus*, the past history of atrazine use had little impact on crickets.

Seasonal distribution of carabids differed among the genera (Figure 3.7). The most commonly collected genus, *Amara* was present in large numbers all year including January, but the population peaked in the early spring during the months of April and May. All of the other genera were scarce or inactive during the winter. *Harpalus*, *Bradycellus*, *Calathus*, and *Bembidion* seemed to peak during the early spring (April and May). Other genera such as *Stenolophus*, *Elaphrus*, *Anisodactylus*, and *Poecilus* seemed to peak in the summer around June and July. *Scarites* appeared to be most common in the late summer and into fall. Many of the less common genera appeared to peak during the summer but numbers were too low to be sure of the seasonal trend.

Location 2

At location 2, there was a significant difference between cover crop histories with significantly more carabids collected in plots with no history of a winter cover crop than in plots with a history of a cover crop (Table 3.4). Pitfall trap samples showed slightly increased numbers of carabids in no-till sub-plots but there were no significant differences between no-till and tilled sub-plots or between the three histories of herbicide induced weed densities. Analysis of wolf spiders (Lycosidae) showed that there was a significant difference in the number of spiders collected in the two tillage treatments as well as plots with a history of a cover crop (Table 3.4). More wolf spiders were collected in sub-plots with no-tillage than in the tilled sub-plots. Plots with a cover crop history had significantly more spiders. Herbicide induced weed density histories did not affect wolf spider numbers. There were no significant interactions between the three treatment factors for carabids or wolf spiders at location 2.

Location 3

Samples taken from location 3 showed a significant difference in carabid numbers between tillage treatments (Table 3.4). Tilled sub-plots had more carabids than the no-till sub-plots. There was no significant difference between the three herbicide induced weed density histories or the presence or absence of a cover crop history although there were slightly more carabids in plots with residues created by the cover crop history. Wolf spiders were collected significantly more in no-till sub-plots and in plots with a cover crop history. There were no differences in the number of wolf spiders found in the three different herbicide induced weed density histories. There were no significant interactions between the three treatment factors for carabids or wolf spiders at location 3.

Discussion

In this study the different agronomic treatments did not directly affect the carabid, wolf spider, or cricket populations. It was the history of the different treatments and the types and amounts of residues left behind from these treatments that were significant in this study. As explained in the methods, during the time the fall traps were in operation all plots were being sprayed on a bi-weekly basis with glyphosate. This left little living plant matter during the majority of the test for carabids to interact with and no fresh production of weed seeds of any kind. Currie and Klocke (2005) reported that during the agronomic experiment, corn grown in the presence of a winter cover crop, but without the application of atrazine resulted in a three-fold reduction of weed biomass. However, application of either rate of atrazine masked any weed control effects created by the cover crop, giving over a 15-fold reduction in weeds. One hundred percent weed control was reported in 2 of the 9 location-years when the high rate of atrazine was applied along with the presence of a winter cover crop. During the three-year agronomic study, weed and cover crop biomass measurements were taken at the end of each season at each location. Others have defined a strong correlation between the biomass of the predominate weed in this experiment, *Palmer amaranth* and its seed production (Massinga et al. 2001). In addition, Currie and Klocke (2005) showed that corn yields were consistently the most in plots treated with the highest rate of atrazine and grown with the presence of a winter wheat cover crop. These plots would then be expected to have the largest amount of ground residue at the end of the experiment. Inversely, plots with no herbicide applications and no winter cover

crop consistently had the least corn yields, and the most weed populations. Because Palmer amaranth (*Amaranthus palmeri*) produces less biomass than corn, this resulted in much less ground residue (Massinga and Currie 2002). At the end of the study, half of all these plots were tilled. The combination of these factors could lead to a number of different ground residue conditions ranging from large amounts of weed and corn debris, where no-till left weed seeds available on the soil surface, to conditions where tilled ground had only a minor amount of corn stubble remaining on the soil surface. As seen from the results of this study, this wide range in soil residue had a variety of effects upon the different genera of carabids.

Location 1

In almost half of the genera studied, the no-till sub-plots were beneficial to carabid populations. This is not surprising, as multiple studies have shown these insects to have increased densities in no-till experiments compared to tilled experiments (Brust et al. 1985, Stinner and House 1990, Anderson 1999, and Holland and Reynolds 2003). The genera *Amara*, *Anisodactylus*, *Harpalus*, and *Calathus* were found more in no-till sub-plots. These carabids are known to prefer habitats with increased humidity, possibly because it is better suited for oviposition and for larval development (Holland 2002). The presence of seeds left behind in weedy plots may also have provided an important food source for those insects (Tooley and Brust 2002, Holland 2002). This is especially true for *Amara*, *Anisodactylus*, and *Harpalus*, which rely on seeds as an important food source both as larvae and adults (Luff 2002). Another potentially important factor could be the ability of the carabids to get to the seeds left behind from various herbicide induced weed densities. White et al. (2007) found that individuals in the genus *Amara* and *Anisodactylus* consumed more seeds of both pigweed and velvetleaf when they were placed on the soil surface versus 1.0 cm below the soil surface. Tillage would incorporate a lot of seed into the soil where they would not be as readily available to omnivorous carabids. The genus *Calathus* is predatory in all life stages and may find more invertebrates to feed on in plots that are not tilled (Luff 2002). The genus *Stenolophus* was collected more frequently in tilled sub-plots, although this was only significant at the $P=0.095$ level. This genus includes a beetle commonly called the seedcorn beetle. As a larva, this beetle feeds on germinating corn seed or young plants, but as an adult it feeds on other insects (Pope 1998). Tillage is commonly used by growers to make left over corn seed or volunteer corn germinate so that it will not be a

weed in the upcoming corn crop. If the tilled sub-plots in this experiment had more germinating corn seed, it would make a better habitat for the larval seedcorn beetles.

There were five genera in this experiment that had a significant response to herbicide induced weed density histories. *Amara*, *Bradycellus*, *Scarites*, *Stenolophus*, and *Calathus* numbers were most in the plots with histories of high weed density induced by no past herbicide applications. The herbicide used in the agronomic study was atrazine, which has a very low toxicity to insects and therefore did not directly kill the carabids or have any residual effect on these insects. It is likely that the herbicide effects were due to the reduced weed densities and therefore depleted seeds which served as a food resource for many genera of carabids such as *Amara*. Furthermore, the wheat planted as a cover is an indicator species and is extremely sensitive to atrazine injury and is often used as an index of the presence of atrazine.

Measurements of wheat biomass were often increased by the past history of atrazine use in the previous study due, possibly, to reduced water use by weeds, which was then allocated for later use by the wheat (Currie and Klocke 2005). Weed biomass is very highly correlated with weed seed production (Massinga et. al 2001). In addition, weed seeds found in high weed density plots could be attracting other seed-eating invertebrates, creating a food source for carabids that feed on other insects such as *Scarites*, *Stenolophus* and *Calathus* (Luff 2002). *Bradycellus* is a diverse genus with different species being common to different habitats (Thiele 1977). The species collected during the sample period are likely those that prefer higher levels of surface residues.

While the historical use of a winter wheat cover crop never resulted in reduced carabid numbers, it only increased them significantly in two of the ten genera, *Harpalus*, and *Poecilus*. As discussed above, the genus *Harpalus* is known to prefer habitats with higher levels of ground cover. However, Currie and Klocke (2005) reported that the presence of a cover crop reduced weeds by at least 3-fold in the absence of atrazine use and therefore would reduce seed food resources for this omnivorous genus. In plots with cover crop alone, this 3-fold reduction did not provide commercial levels of weed control. Where a cover crop and atrazine were used together a 15-fold reduction was produced. In two of the 9 location- years, 100 % weed control was achieved with this combination (Currie and Klocke 2005). *Poecilus* was more commonly found in the plots with a history of a cover crop although it is only significant at the $P=0.07$ level. A past study looking at several individual species within the genus *Poecilus* found that habitat

preferences varied among the different species (Carmona and Landis 1999). The results of this experiment may show *Poecilius* to be more common in cover crops because there were higher numbers of the particular species that prefer increased ground debris.

The complex relationship between carabid genera and ground residues is further explained by the two-way interactions found in three genera. In *Amara* and *Calathus*, most insects were reported in plots with no tillage but with high rates of herbicide, creating an environment with little weed biomass, but the available seeds and plant residues would be left on the soil surface. Although it is known that these two genera feed upon weed seeds and therefore would be expected to prefer high weed density plots, this combination could also supply plenty of food while creating a more preferable habitat in terms of finding food, hiding places, and acceptable oviposition places. In *Harpalus*, the results are slightly different. This genus is found more frequently in no-till plots with a history of high weed densities created by no herbicide application and with the history of a cover crop. This would create a ground environment with some weed control provided by the cover crop but there would still be plenty of seeds and plant residue left on the soil surface because there was no tillage. This fits in with the previously described ideal environment for *Harpalus* (Holland 2002, Brandmayer 1990).

In several genera there were no significant effects from any of the treatment factors. In the genus *Bembidion* there were only 35 individuals collected over the entire sampling period so there were too few individuals to get any statistical results. The Genus *Elaphrus* is composed of small beetles that look very similar to a Tiger beetle (Cicindellidae). They have large compound eyes that give them great field vision and may make it easier for these insects to fly around the field in search of prey or to escape predators (Forsythe 1987). It is also possible that with proficient vision they may have physically avoided the traps in many instances. This genus is so readily mobile it may be moving around between plots, making it difficult to detect any of the treatment effects

Crickets responded only to tillage treatments. They were collected more in no-till sub-plots than in tilled sub-plots. Crickets were feeding on weed seed and as seen with seed feeding carabid genera, they may have been collected more frequently in sub-plots that were not tilled because it was easier to obtain seed on the soil surface rather than having to locate seeds that had been tilled into the soil. Unfortunately, we do not have usable data from location 2 and 3 to corroborate these observations.

Locations 2 & 3

At location 2, most carabids were collected from sub-plots with no previous history of a cover crop. In all of the commonly collected genera from location 1 the history of a cover crop never significantly reduced population numbers although numerically there were more individuals from the genera *Amara*, *Stenolophus*, and *Calathus* collected from plots with no history of a cover crop (Table 3.3). Location 2 was the least productive location of the three (Currie and Klocke 2005). This was attributed to lower water use efficiency (WUE) than the other locations. It was assumed that there was less uniform water intake because of the variability in slope, lower sand content, and higher irrigation application rates that caused more water runoff. Decreased corn yield and reduced wheat cover crop dry matter would lead to less residue on the ground and would have created habitats for the carabids with far less residue available than a number of the plots in location 1.

At location 3, more carabids were collected in tilled sub-plots than in no-till sub-plots. In respect to tillage treatments, it seems as though different genera may respond differently to tillage. It is important to note that even with tillage there still can be a number of different residue types present. This makes it even more difficult to draw definite conclusions based on tillage alone. Location 1 showed that carabids were more common in a no-till system in 7 of the 10 genera studied (Table 3.3). However, in the other 3 genera there were more individuals collected when there were tillage treatments (only significant in one genus). The results from locations 2 and 3 suggest that the amazing diversity of carabids in terms of their habitat preferences may make it difficult to draw general conclusions about the entire family. The overall results for this experiment suggest that either carabids have little impact when looking at the entire family or that more work is needed to further define the impact of these inputs on the individual carabid genera collected in this study.

Wolf spiders followed a little more closely to the expected trend based on past research. At all locations, wolf spiders were collected significantly more in sub-plots with no tillage and with the history of a cover crop. However, different herbicide induced weed density histories did not have any effect on populations of spiders at any location. These results further support the work of Hummel et al. (2002) that showed that wolf spiders prefer weedier habitats with more ground cover. This could be due, at least to some degree, to the fact that insects and other food

sources for these spiders may be more common or easier to locate under no-till conditions with the history of a cover crop.

Figures and Tables

Figure 3.1 A pitfall trap tube installed in a plot.



Figure 3.2 The masonite cover over a pitfall trap.



Figure 3.3 - Interactions between tillage and history of herbicide induced weed density in the genera (A) *Amara* and (B) *Calathus*

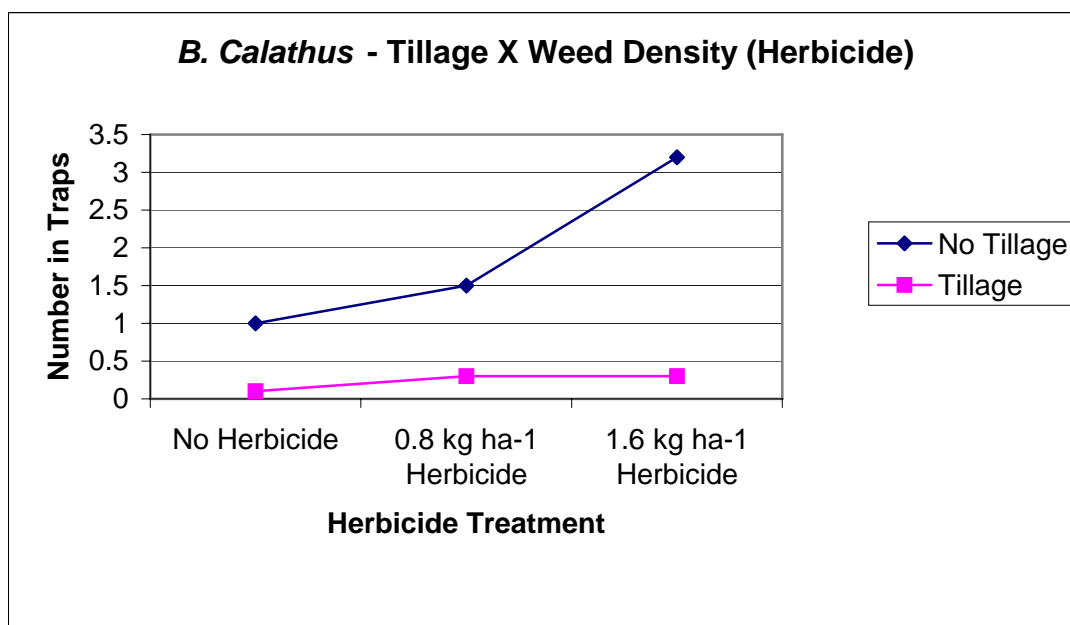
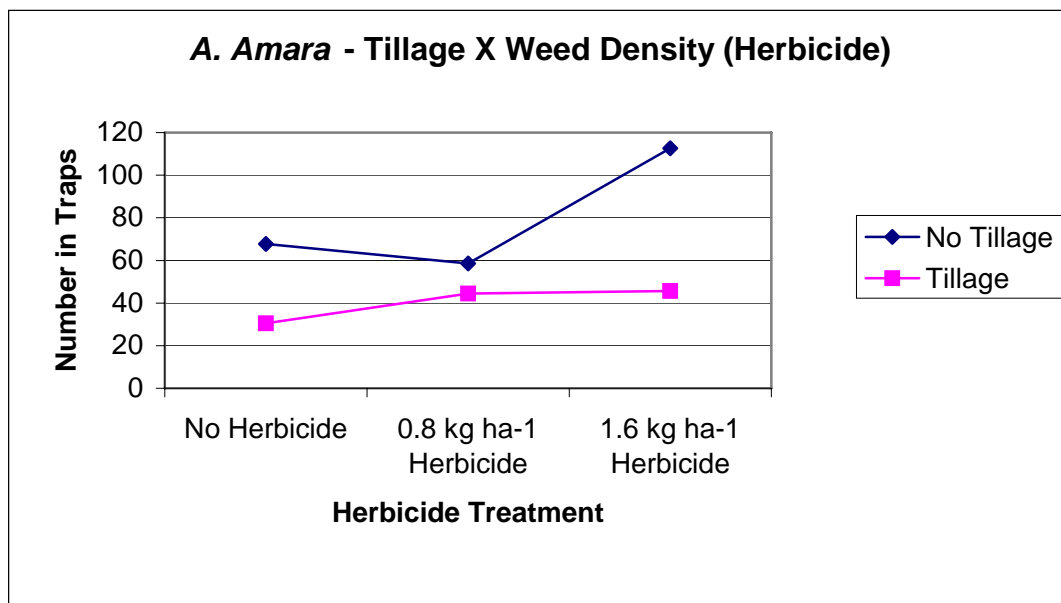


Figure 3.4 Interactions between (A) tillage and history of herbicide induced weed density and (B) tillage and history of winter cover crop in the genus *Harpalus*.

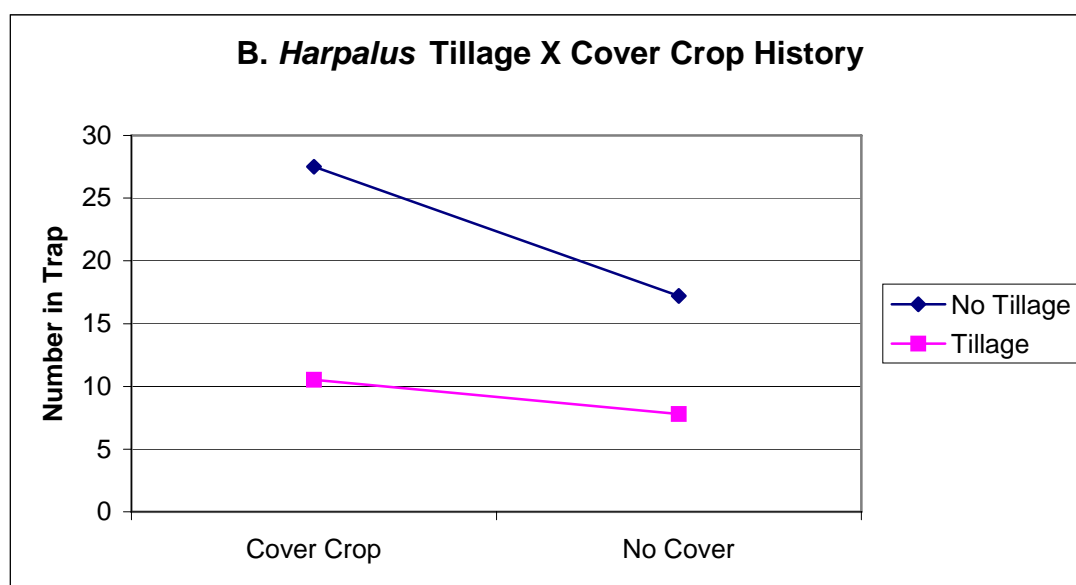
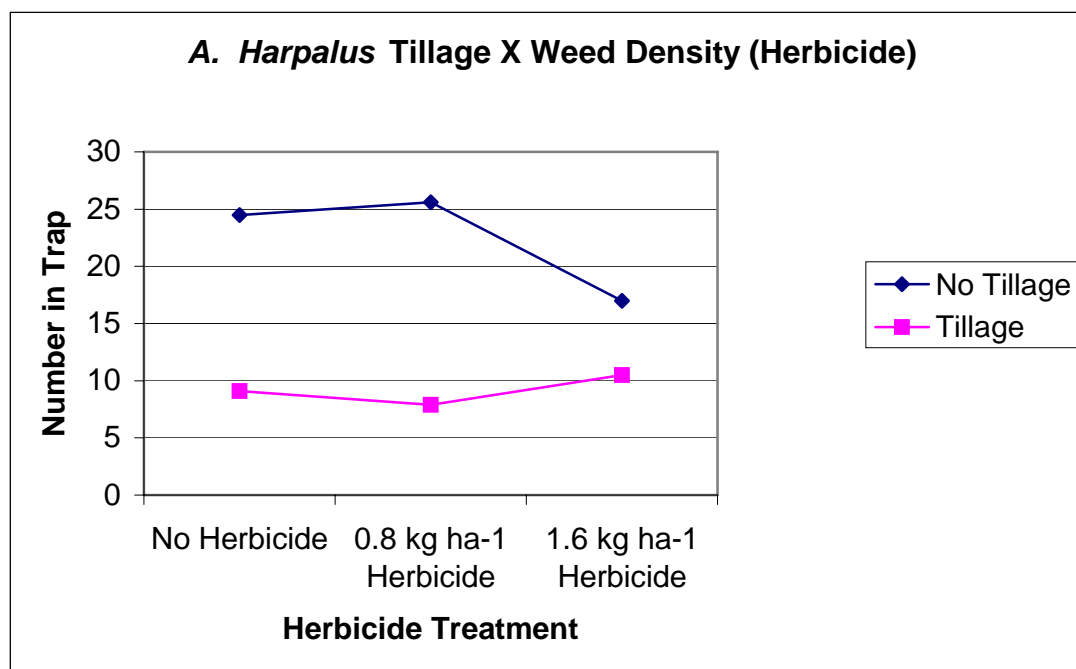


Figure 3.5 Interactions between tillage, history of herbicide induced weed density, and history of winter wheat cover crop in the genus *Anisodactylus*, (A) with a history of a cover crop and (B) without a history of cover crop.

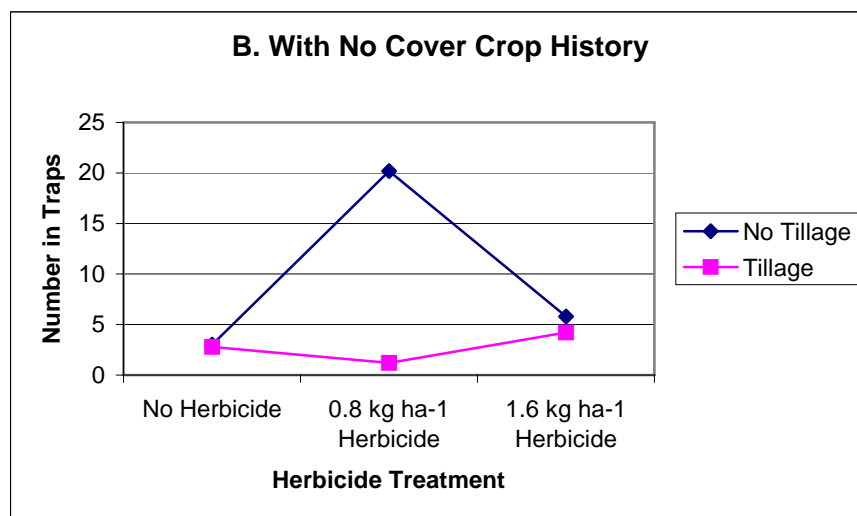
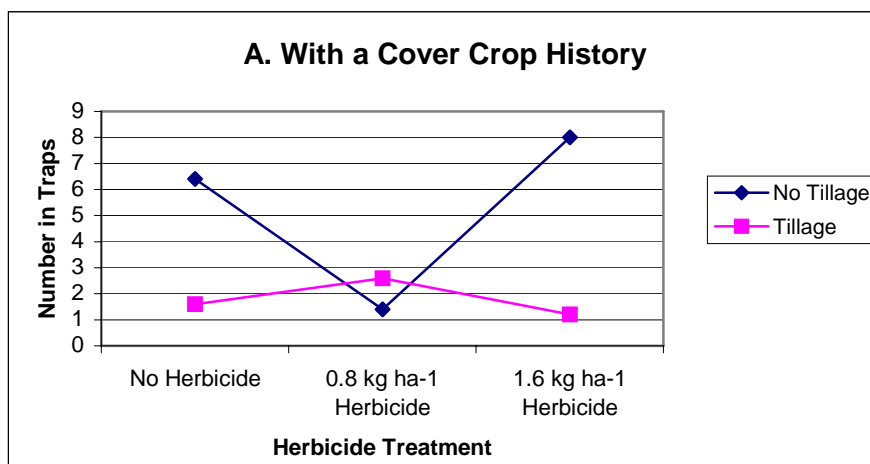


Figure 3.6 Interactions between tillage and history of herbicide induced weed density in Lycosidae

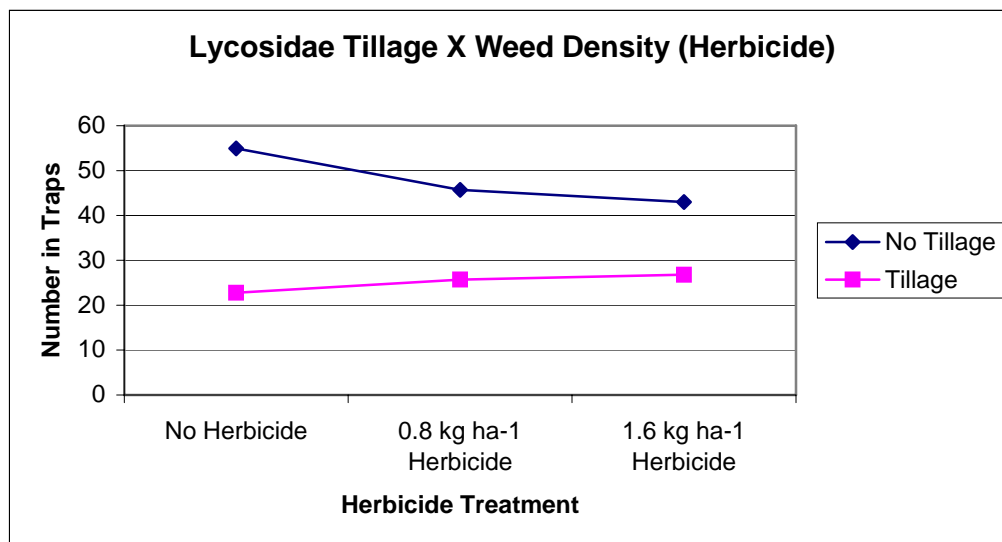
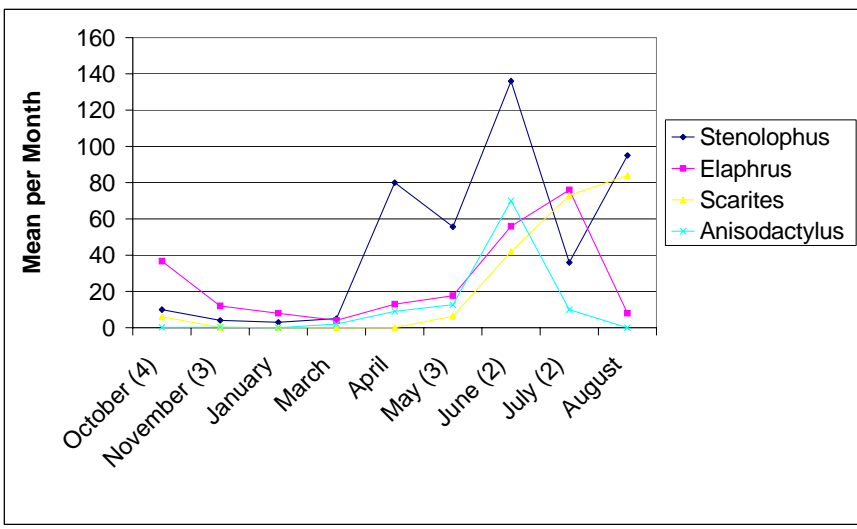
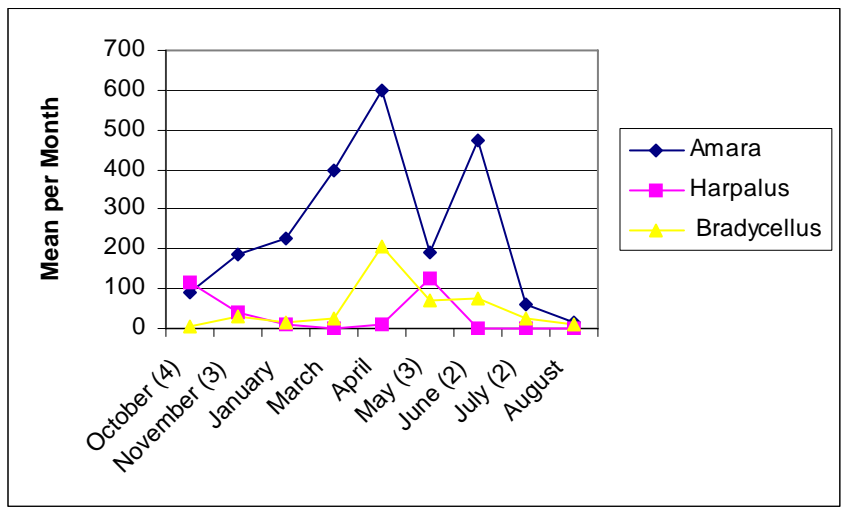


Figure 3.7 Seasonal occurrences of the 10 most common carabid genera collected at location 1



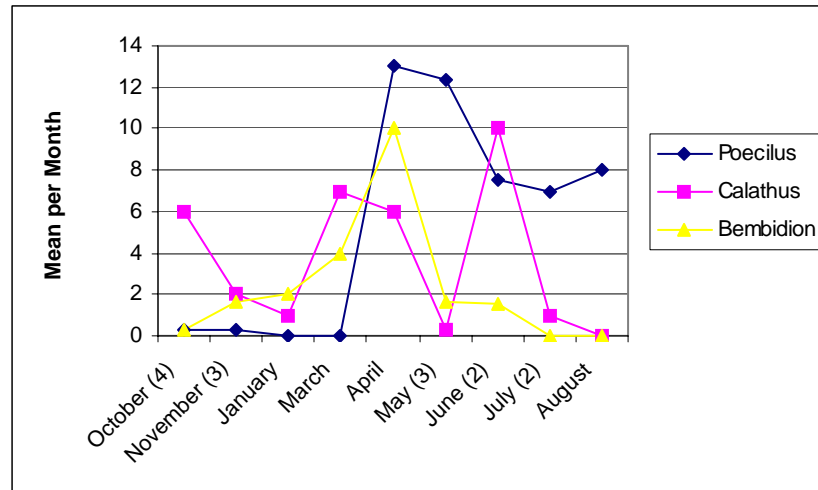


Table 3.1 The list of carabid genera collected from location 1, October 2000- August 2001. Includes the season total number of specimens collected and the percent of total.

Genus	Season Total	Percent
<i>Amara</i> spp.	3802	49.4
<i>Harpalus</i> spp.	969	12.6
<i>Bradycellus</i> spp.	777	10.1
<i>Stenolophus</i> spp.	750	9.7
<i>Elaphrus</i> spp.	533	6.9
<i>Scarites</i> spp.	358	4.6
<i>Anisodactylus</i> spp.	211	2.7
<i>Poecilus</i> spp.	94	1.2
<i>Calathus</i> spp.	67	0.8
<i>Bembidion</i> spp.	35	0.5
<i>Lebia</i> spp.	32	<0.5
<i>Calosoma</i> spp.	19	<0.5
<i>Cyclotrachelus</i> spp.	16	<0.5
<i>Pterostichus</i> spp.	15	<0.5
<i>Chlaenius</i> spp.	8	<0.5
<i>Microlestes</i> spp.	7	<0.5
<i>Abacidus</i> spp.	5	<0.5
<i>Cicindela</i> spp.	2	<0.5
<i>Euryderus</i> spp.	1	<0.5
<i>Pasimachus</i> spp.	1	<0.5
Total	7702	100

Table 3.2 P-values for the three-factor analysis of variance for carabid genera collected from location 1, October 2000- August 2001. There were two levels of tillage, three levels of weed density and two levels of cover crop. P-values that are significant (>0.05) are in bold.

P-Values				
Carabidae Genus	Tillage	Weed Densities	Cover Crop History	Interactions
<i>Amara</i> spp.	<0.0001	0.002	0.784	Till.*Weed 0.015
<i>Anisodactylus</i> spp.	0.025	0.576	0.241	Till*Weed*Cover 0.039
<i>Bradycellus</i> spp.	0.533	0.087	0.955	N.S.
<i>Elaphruys</i> spp.	0.496	0.626	0.102	N.S.
<i>Harpalus</i> spp.	<0.0001	0.398	0.003	Till*Weed 0.084 Till*Cover 0.079
<i>Scarites</i> spp.	0.320	0.072	0.943	N.S.
<i>Stenolophus</i> spp.	0.095	0.004	0.521	N.S.
<i>Bembidian</i> spp.	0.686	0.457	0.762	N.S.
<i>Calathus</i> spp.	<0.0001	0.031	0.59	Till*Weed 0.067
<i>Poecilus</i> spp.	0.507	0.655	0.072	N.S.

Table 3.3 Mean number of carabids collected throughout the sampling year for the three treatment factors - location 1, October 2000- August 2001.

Carabidae Genus	Means						
	No Tillage	Tillage	High Weed Density (No Herbicide)	Moderate Weed Density (0.8 kg ha ⁻¹ Herbicide)	Low Weed Density (1.6 kg ha ⁻¹ Herbicide)	No Cover Crop History	Cover Crop History
<i>Amara</i> spp.	79.6 a	40.2 b	79.2 a	51.5 b	49.1 b	60.9 a	58.9 a
<i>Anisodactylus</i> spp.	7.5 a	2.3 b	4.8 a	6.4 a	3.5 a	3.5 a	6.2 a
<i>Bradycellus</i> spp.	11.4 a	12.9 a	15.7 a	11.4 a b	9.4 b	12.2 a	12.1 a
<i>Elaphruys</i> spp.	9.6 a	8.1 a	10.4 a	8.2 a	8.0 a	7.0 a	10.7 a
<i>Harpalus</i> spp.	22.4 a	9.2 b	16.8 a	16.8 a	13.8 a	12.5 b	19.0 a
<i>Scarites</i> spp.	6.4 a	5.5 a	7.5 a	5.4 b	5.0 b	6.0 a	5.9 a
<i>Stenolophus</i> spp.	10.8 b	13.7 a	16.5 a	10.0 b	10.3 b	12.8 a	11.7 a
<i>Bembidian</i> spp.	0.8 a	1.0 a	1.0 a	0.4 a	1.4 a	0.8 a	1.0 a
<i>Calathus</i> spp.	1.9 a	0.2 b	1.8 a	0.9 b	0.6 b	1.2 a	1.0 a
<i>Poecilus</i> spp.	1.7 a	1.4 a	1.4 a	1.8 a	1.6 a	1.2 b	1.9 a

Means in the same row but within each treatment factor (tillage, weed density or cover crop) followed by the same letter are not significantly different (>0.05), LSD

Table 3.4 P-values for the three factor analysis of variance for carabids (Coleoptera: Carabidae), wolf spiders (Araneae: Lycosidae) and crickets (Orthoptera: Gryllidae) collected from locations 1, 2, and 3.

	P-Values				Means						
	Tillage	Weed Density	Cover Crop History	Inter-actions	No Tillage	Tillage	High Weed Density (No Herbicide)	Moderate Weed Density (0.8 kg ha ⁻¹ Herbicide)	Low Weed Density (1.6 kg ha ⁻¹ Herbicide)	No Cover Crop History	Cover Crop History
Coleoptera: Carabidae											
Location 1	<0.0001	0.0005	0.336	N.S.	152.1 a	94.5 b	155.0 a	112.6 b	102.4 b	118.1 a	128.5 a
Location 2	0.724	0.829	0.01	N.S.	323.8 a	315.73 a	316.8 a	313.2 a	329.5 a	350. a	289.0 b
Location 3	0.031	0.298	0.527	N.S.	117.6 b	148.4 a	133.6 a	119.3 a	146.1 a	128.6 a	137.4 a
Aranea: Lycosidae											
Location 1	<0.0001	0.474	0.014	Till*Weed 0.051	47.9 a	25.1 b	38.8 a	35.7 a	35.0 a	33.1 b	39.9 a
Location 2	<0.0001	0.889	0.047	N.S.	18.8 a	10.7 b	14.5 a	14.5 a	15.4 a	13.0 b	16.5 a
Location 3	0.002	0.801	0.043	N.S.	11.9 a	8.0 b	10.5 a	9.8 a	9.6 a	8.8 b	11.2 a
Orthoptera: Gryllidae											
Location 1	0.0002	0.969	0.852	N.S.	22.7 a	14.6 b	18.4 a	19.0 a	18.6 a	17.1 a	20.2 a

Means in the same row but within each treatment factor (tillage, weed density or cover crop) followed by the same letter are not significantly different (>0.05), LSD

CHAPTER 4 - Conclusions

Conclusions

The use of cover crops and the reduction of tillage are considered valuable tools that aid in reducing erosion and water runoff. These practices also increase water infiltration, and the soil's organic matter. This experiment used *Bromus tectorum* L. (downy brome) as a winter cover crop in corn production because it is a self-pollinating winter annual that should be self-sustaining and should not be competitive with the corn crop. This experiment demonstrated that the use of downy brome increased levels of residue left on the soil's surface. However, there was no correlation between the presence of downy brome residue and increased surface water. Downy brome populations continued to decrease throughout the experiment and the year following this experiment there was no downy brome observed in any of the plots. This suggests that this plant is not capable of sustaining itself as a cover crop in a corn production system and that only a minimal amount of control inputs may be needed over a three-year period to cause localized extinction of downy brome.

In this study, the WCR larvae, *Diabrotica virgifera* LeConte, appeared to cause greater damage to corn roots when there was a downy brome cover crop present. Although this was indicated in only one of two trials (north), it appears that the absence of a statistical difference between damage ratings in the south trial was due to a lack of a significant difference in downy brome or detritus residue between the high and low downy brome treatments. It could have also been due to small or spotty WCR populations. Possible reasons why larval damage was significantly higher in plots with the downy brome cover crop are as follows. It has been shown that, in the absence of corn roots, the WCR is capable of surviving up to the second instar on a number of weedy grass roots (Clark and Hibbard 2004, Oyediran et al. 2004, Wilson and Hibbard 2004). In sub-plots with downy brome, early instar corn rootworm larvae may be feeding on downy brome roots until the corn roots have developed. Higher damage may also be the result of female oviposition preferences. The residue created by the downy brome cover crop may create a preferable site for oviposition compared to corn residue alone. Additional studies looking at adult behaviors, soil egg counts, and larval survival rates need to be conducted in

order to better determine the exact cause of greater larval damage in corn plots with a downy brome cover crop.

During the three years of this experiment that spider mites and predatory mites were collected, natural populations remained low and never reached economic thresholds. However, these studies indicated that the species of spider mites studied, the Banks grass mite, *Oligonychus pratensis* (Banks), and the twospotted spider mite, *Tetranychus urticae* Koch, as well as the predatory mites, *Neoseiulus* spp. did overwinter on downy brome plants growing within the corn crop. Spider mites and predatory mites did migrate into the corn at the beginning of the season but there were no differences in spider mite or predatory mite population levels between corn grown with the cover crop and corn grown without the cover crop. This may have been due to the close proximity of the plots, which allowed the mites on downy brome plants to passively migrate by aerial dispersal to nearby plots that did not have downy brome as a cover crop. These findings suggest that the use of a cover crop may benefit the biological control of spider mites by predatory mites because it creates favorable habitats for overwintering populations of predatory mites. Further studies are needed looking at the use of weedy cover crops as overwintering sites for both spider and predatory mites before any conclusions can be made.

The second part of this study looked at how plant residues created by a history of a winter wheat cover crop, history of weed densities caused by herbicide treatments, and tillage treatments affected common soil dwelling arthropods such as carabids (Coleoptera: Carabidae), wolf spiders (Araneae: Lycosidae), and crickets (Orthoptera: Gryllidae). Pitfall traps were utilized for this and were monitored for approximately one year after the conclusion of an agronomic study designed to evaluate the effects of a wheat cover crop on weed and water management. What became readily apparent is that there are many complex relationships involved. There were many different types and levels of ground residue created by the interactions of the winter wheat cover crop, herbicide treatments, and tillage. In addition, there were many complex reactions between the carabids, wolf spiders, and crickets and their environment, making it very difficult to determine which environmental factors were most affecting these various arthropods.

At location 1, carabids were collected and identified to the genus level. Among the ten most common genera collected, the genera *Amara*, *Anisodactylus*, *Harpalus*, and *Calathus* were

found more commonly in sub-plots that did not receive a tillage treatment at the beginning of the experiment. These genera are known to be seed feeders and it is possible that the lack of tillage left more seeds available on the soil's surface. The genus *Stenolophus* was collected more in sub-plots that were tilled. Some beetles in this genus are known to feed on germinating corn seed. Tilled sub-plots probably had more germinating corn seed, providing more food sources than the no-tilled subplots. The genera *Amara*, *Bradycellus*, *Scarites*, *Stenolophus*, and *Calathus* were collected more frequently in plots that had a history of high weed density created by no past herbicide applications. The herbicide had no direct effect on the carabids. However, the herbicide used in the past reduced weed densities and therefore may have reduced the amount of weed seed available for feeding. The past use of a winter wheat cover crop never reduced carabid populations but it only significantly increased populations in the genera *Harpalus* and *Poecilus*. The residue created by the cover crop may have been so thick that it impeded the movement and ability to find food for many of the carabids. The complex relationship between carabid genera and ground residues is further explained by two-way interactions found in the genera *Amara*, *Calathus*, and *Harpalus*. In *Amara* and *Calathus* the most carabids were collected in plots with no tillage and the history of low weed density created by high herbicide treatments. *Harpalus* was found more frequently when there was no tillage but a high history of weed density created by no herbicide treatment.

When the carabids collected from locations 1, 2 and 3 were analyzed at the family level; there was a great deal of variation. At location 1, more carabids were collected in no-till subplots with a history of high weed densities created by no past herbicide treatments. At location 2, the only significant difference was that more carabids were collected in plots with no history of a cover crop. The results of location 3 are opposite from the results of location 1. Here, more carabids were collected in plots with tillage treatments. These wide ranging results suggest that the genera that make up the family Carabidae are very diverse. It appears that in order to make conclusions about carabids, the genera need to be looked at separately.

Wolf spiders from all three locations followed a similar trend. At all locations these spiders were collected more frequently in plots with no tillage treatment and with the history of a winter wheat cover crop. This suggests that wolf spiders prefer more ground cover. This may be because there are greater prey densities under these conditions.

Crickets were only collected at one location where they were more common under no-till conditions. Many species of ground crickets are known to be seed feeders. These results suggest that this is because there are more seeds available for crickets to feed on the soils surface when soil is not tilled. Additional research needs to be conducted in order to confirm this hypothesis.

The overall results of these two experiments point out something important. Agroecosystems are complex and there are a great number of factors that may affect insect populations. This research suggests that the addition of a cover crop will impact arthropod populations. When looking at predatory mites, carabids, wolf spiders, and crickets, there seems to be the potential for a cover crop to lead to better pest control, weed reduction, and overall increased insect diversity. However, there are some pests such as the WCR and the spider mite complex that may also benefit from the presence of a cover crop and increase crop damage. The decision to use cover crops in agroecosystems must take the arthropods examined here, along with many other potential beneficial and harmful insects, into consideration.

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