EFFECTS OF ALTERNATIVE MANAGEMENT PRACTICES ON THE ABUNDANCE OF ARTHROPODS IN A MIXED-CROP AGROECOSYSTEM

by

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

of

Master of Science

in

Entomology

MONTANA STATE UNIVERSITY
Bozeman, Montana

April 2013

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of a thesis submitted by

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

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April 2013

ACKNOWLEDGEMENTS

I would like to thank my major advisor, Dr. Kevin M. O'Neill for his help and guidance throughout this research program. I would also like to thank my committee members, Dr. Hayes Goosey, Dr. Patrick Hatfield, Dr. Zachariah Miller, Dr. Robert K. D. Peterson, and Dr. Kevin Wanner,

I would also like to thank my parents, brothers, and friends for their moral support. A special thanks to Dr. Casey Delphia and Ruth O'Neill, who gave assistance on insect identification and data analysis. I am also thankful to Dr Mike Ivie, and fellow Entomology graduate students, Anuar Morales and Frank Etzler for their assistance with the wireworm portion of the study. To the Fort Ellis research program fellow graduate students, Joy Barsotti, Erin Nix, and Devon Ragen and to all the summer workers, Jillian Hatfield, Jennifer Keithy, Kellon Marlow, Nirap Sainju, Megan Scherting, and Emmet Wester a very special thanks from me. Also not to forget, Linda McDonald and the people at the LRES front desk who were more than helpful. My special thanks to the LRES department head, Dr. Tracy Sterling. I would also like to express my gratitude to the sponsor of this research USDA/CAR MAES.

Last but not the least, as an entomologist, I would like to extend my deepest gratitude, appreciation, and admiration to the great world of arthropods.

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ABSTRACT

We evaluated the effects of alternative management practices on the abundance and diversity of arthropods in a mixed-crop agroecosystem in studies conducted in 2010 and 2011 at the Fort Ellis Experimental Station near Bozeman, MT. In one study, we quantified arthropod relative abundance in plots across three summer fallow weed management practices (sheep grazing, mechanical/tillage, and chemical herbicide) incorporated into a three-year rotation in two different sets of crops. Arthropod abundance was compared among 1) the spring wheat plots under the three management schemes with the rotational treatments (continuous spring wheat and rotational spring wheat), 2) the pea/hay barley plots under the different weed management schemes, and 3) fallow plots under the three weed management schemes. In a second study, we examined arthropod relative abundance in plots with alternative alfalfa cultivars (Cimarron SR, HayGrazer, and Shaw). Sweep net samples were taken to compare the abundances of the most common insect orders and families (as well as a few abundant species and genera). In addition, baited traps were used to compare the abundance of click beetle larvae or wireworms (Coleoptera: Elateridae) within the different management schemes and treatments. This study demonstrated that the number of arthropods in the continuous spring wheat was lower compared to the rotational spring wheat. Arthropod abundance in the pea/hay barley plots under the three different managements was inconsistent from one year to the other. In the summer fallow plots, abundance of most arthropod taxa was the lowest in the mechanically-treated plots, whereas there was no difference in the number of most arthropods present between the chemical and grazed plots which shows that sheep grazing was equally effective as the application of herbicides in reducing arthropod numbers on summer fallow plots. The abundance of most arthropod taxa did not differ among the Cimarron SR, HayGrazer, and Shaw alfalfa cultivars except for Aphididae, Formicidae, and Ichneumonidae in 2010. Nine species of wireworms were collected from the study site with *Aeolus mellilus* Say being the most common. In both years, *A. mellilus* was most abundant in the continuous spring wheat plots compared to the other plots.

INTRODUCTION

Traditional pest management in small grains, pulse crops, and alfalfa has relied heavily on the use of pesticides. Since pesticides are highly effective in controlling immediate pest infestations, easily accessed, convenient, and easy to use, they have become a grower's most powerful weapon of choice in combating pests. The sensible use of pesticides is one of the major contributing factors that have led to the increase of global agricultural productivity (Pimentel et al., 1992 and Metcalf, 1994).

However, due to overuse and/or lack of knowledge about pesticides and their alternatives, much use of pesticides has been ecologically unsound, leading to repercussions that are detrimental to human health and the environment (Pimentel et al., 1992 and Metcalf, 1994).

Pesticides can be very effective when it comes to killing or eliminating insect pests but, beneficial insects are often killed as collateral damage. Most of the pesticides available today are of chemical origin and are not highly selective as to which organisms they affect. The widespread practice of using chemical pesticides has been known to adversely affect insect pollinators and natural enemies that prey on or parasitize pest insects (Metcalf, 1994). Studies conducted using both natural enemy and pollinator models showed that exposure to sublethal insecticide levels could impede the normal learning, behavioral, and neurophysiological performances of beneficial arthropods (Desneux et al., 2007). For example, Stapel et al. (2000) demonstrated that exposures to sublethal doses of systemic insecticides severely impaired the host foraging ability and also reduced the life span of the parasitoid, *Microplitis croceipes* Cresson (Hymenoptera: Braconidae).

The ability of insects to evolve resistance against conventional pesticides further exacerbates the problem of relying too heavily on chemical control. The continuous and unregulated use of pesticides combined with the short generation time and high fecundity of insects have led to the increased selection pressure that favors genes that confer resistance. There are more than 500 species of insects and mites that have already acquired some level of resistance to insecticides (Georghiou, 1990). For example, the green peach aphid, *Myzus persicae* Sulzer (Hemiptera: Aphididae) is the champion of the agricultural pest world in developing resistance to insecticides and is documented as being resistant to at least 71 different synthetic insecticides (Georghiou & Lagunes-Tejada, 1991). Two other insects known for their rapid ability in building resistance to insecticides are the diamondback moth, *Plutella xylostella* Linnaeus (Lepidoptera: Yponomeutidae) and the Colorado potato beetle, *Leptinotarsa decemlineata* Say (Coleoptera: Chrysomelidae). As of 1989, the diamondback moth was reported to be resistant to 51 different compounds (Georghiou & Lagunes-Tejada, 1991) and the Colorado potato beetle, as of 2008, was resistant to 52 compounds used in all major insecticides classes (Alyokhin et al., 2008).

Chemical management of pest insects can also be time-consuming and labor demanding as it requires intensive field monitoring of pest populations to determine the need for and timing of pesticide applications during years of increased pest outbreaks and/or crop values (Pedigo 2002). As a result of the above concerns, the current trend, in accordance with integrated pest management practices is to minimize the sole reliance on pesticides by incorporating other means of pest management strategies such as cultural, mechanical, and biological controls. Thus, part of our research is to further investigate the potential for using sheep (*Ovis aries* L.) grazing to reduce both pest numbers and pesticide use. While pesticide use in integrated pest management is a preventative measure, grazing may help reduce or eliminate the economic and environmental costs of pesticide use even in years when pest insect populations are below the economic injury levels (Goosey et al., 2004).

Crop Rotation

Crop rotation, in contrast to continuous monoculture, is the cultivation of the same land with different crops in a planned order,. It is one of the oldest agronomic techniques, dating back thousands of years, and has been effective in protecting crops from pests and diseases while maintaining soil fertility (Bullock, 1992). Rotation schemes are most successful against arthropod pests that have 1) a limited or specific host, 2) long generation cycles, 3) limited dispersal capabilities, and 4) oviposition before the planting of alternative crop (Pedigo, 2002).

The complex of insect pests is interrupted when a non-host crop is grown in the following year. Therefore, the selection of proper crop rotation sequence involving families of non-related crops is sometimes the key solution in effectively controlling the resident-type insect pests which are known to have long life cycles and limited hosts (All, 1989).

Crop rotation may also enhance the effects of natural enemies. For example, increased abundance and effectiveness of natural enemies of Russian wheat aphid, *Diuraphis noxia* Mordvilko (Hemiptera: Aphididae) and greenbug, *Schizaphis graminum* Rondani (Hemiptera: Aphididae), have been observed in cropping systems involving crop rotation (Elliot et al. 1998, Ahern & Brewer, 2002 and Elliot et al., 2002). It is widely accepted that crop rotation allows for sustained production with stabilized or in some cases even increased production profits compared to wheat-fallow and wheat monoculture (Dhuyvetter et al., 1996 and Peterson et al., 1996).

Sheep Grazing on Summer Fallow

Summer fallow refers to the practice of keeping cropland out of production during the regular growing season to conserve the soil moisture and fertility which further increases the chances of a healthy crop production the following year. To allow the land to lie idle and regain the soil moisture and fertility content needed for the following year, producers control weeds that might otherwise reduce the effectiveness of the fallow period. The most common methods of fallow weed management include tillage of the soil and herbicide application. As effective as these methods are, they are also expensive, making fallow weed management the highest variable cost associated with dryland grain production (Goosey et al., 2005).

The alteration of various environmental factors including vegetation community composition, soil compaction, and microclimate caused by the presence of sheep could negatively affect insect pests either directly or indirectly through several potential mechanisms. First, removal of weeds through grazing eliminates the alternative living space and oviposition sites for insect pests, though grazing may also diminish the source of nectar for beneficial insects. Second, sheep may cause the direct mortality of insects located on and within the grazed foliage; eggs and relatively immobile immature stages of insects are especially vulnerable (e.g., alfalfa weevil, *Hypera postica* Gyllenhall (Coleoptera: Curculionidae) larvae on plant surfaces and wheat stem sawfly, *Cephus cinctus* Norton [Hymenoptera: Cephidae] larvae inside plant stems). Third, grazing and associated trampling may cause the destruction and removal of plant cover that serve as refuge for insect pests and increase the likelihood of surface and soil-dwelling insects being eaten by birds (East & Pottinger, 1975). Fourth, vegetation removal via grazing and trampling can severely influence above and below ground microclimate by changing the patterns of isolation and air flow over the soil surface (O'Neill et al., 2003). The alteration of aboveground plant matter also increases the above and below ground diurnal temperature fluctuation which depletes the air and soil moisture (East & Pottinger, 1983). Fifth, grazing by sheep may reduce food availability and quality for pest insects such as grasshoppers either directly through competition or indirectly through changes in plant community composition (O'Neill et al., 2003). Insects located close to and on the soil surface may become vulnerable to being trampled to death or injured by sheep (East, 1980). Trampling also breaks up soil surfaces, exposing insects located close to the soil surface to predation (East & Pottinger, 1975) and to high temperatures that may cause desiccation (e.g., eggs and pupae).

Management of pests by means of grazing has been investigated primarily in grasslands focusing mostly on the subset of insect taxa that are rangeland pests (Onsager, 2000, O'Neill et al., 2003 and O'Neill et al., 2008),. However, other studies on cropland have shown that the elimination of alfalfa stems through winter grazing reduces the incubation and hibernation substrate for the alfalfa weevil eggs and larvae. Natwick et al. (2004), suggested that sheep grazing on winter alfalfa was the best alternative to pesticides in suppressing weevil and aphid populations in the irrigated Sonoran Desert. Not only were sheep as effective as pesticides, the quality of hay was increased through the grazing treatment. Buntin & Bouton (1996), recorded a reduction in weevil larvae numbers by 65% in 'Alphagraze' alfalfa and by 32% in 'Apollo' alfalfa due to spring alfalfa grazing by cattle in Georgia. In Oklahoma, Dowdy et al. (1992) reported that cattle grazing on winter alfalfa caused a 67% reduction in alfalfa weevil eggs, and subsequent larval numbers were 25% lower. Prior to first harvest of forage production alfalfa in Montana, Goosey et al. (2004) showed that winter and spring sheep grazing reduced alfalfa weevil damage without negatively affecting yield or nutritive characteristics of subsequent hay crops. Regardless of whether the sheep were present in fall or spring, there was an increased mortality rate of overwintering wheat stem sawfly larvae due to sheep grazing and trampling in wheat in Montana (Goosey et al., 2005 and Hatfield et al., 2007).

However, despite these encouraging results, studies have not been extended to determine the effects of grazing on broader range of insect pests and impacts on beneficial arthropods remain under studied. Furthermore, the effects of grazing on insects have not been investigated in comprehensive studies, such as those proposed here, that also examine the effect of grazers on weeds, soil nutrients, and compaction.

Therefore, the incorporation of sheep grazing has the potential to reduce pesticide use in cropping systems while alleviating concerns with non-target arthropods, pesticide resistance in insects, and other hidden costs associated with pesticide use. Apart from potentially being one of nature's best biological control agents for weeds and a prospective candidate for the reduction of pesticide use, sheep can easily be integrated into an established farm. The ever increasing lamb and mutton prices due to high demand is another form of encouragement for farmers who are interested in earning additional side income. The relatively small investment required and the ease of rearing sheep has substantial potential in creating new, long-term, lucrative entrepreneurial opportunities for rural families. Thus, we propose to extend previous studies of the effect of sheep grazing on arthropods by comparing grazing to alternative cultural practices (i.e., tillage) and chemical fallow.

Alfalfa

Alfalfa or lucerne (*Medicago sativa* L.) is recognized as the world's oldest forage crop and its domestication most likely predates recorded history (Michaud et al. 1988). Currently, it is the most important forage crop in temperate regions and hence it is often dubbed the "Queen of Forages". In the United States, alfalfa, which is worth $7 billion annually, constitutes about 2.5% of the agricultural land (USDA, National Agricultural Statistical Service, 2007) and was the fourth most economically important crop cultivated in the United States after corn, soybean, and wheat as of 2011 (United States Department of Agriculture Crop Values 2011 Summary www.nass.usda.gov).

Alfalfa, a perennial legume, is extremely valuable as it offers high quality forage for all classes of livestock. It is exceptionally rich in vitamins, minerals, and protein. It is also high in cell solutes but low in cell wall and neutral detergent fibers which allows for excellent animal intake and greater digestibility rate (Conrad & Klopfenstein, 1988). Apart from being a great forage crop, alfalfa as a legume harbors symbiotic bacteria in its root nodules, which have the ability to fix atmospheric nitrogen and subsequently improves the soil fertility. This soil improving characteristic of alfalfa also benefits subsequent crops in crop rotation systems involving alfalfa. As a perennial crop, alfalfa is normally grown for several years without the need of reseeding, which further reduces the cost of cultivation. Alfalfa grows vigorously and strong alfalfa stands out-compete weeds. Maintaining healthy vigorous stands reduces the need for herbicides. The biomass productivity of alfalfa is unrivaled among forage legumes, with record yields of 22,000 kg dry matter per hectare without irrigation and 54,000 kg dry matter per hectare with irrigation (Small, 2011). Alfalfa is also drought tolerant and winter hardy.

The domestication of alfalfa is assumed to have occurred independently several times and its origins can be traced to the Near East regions which include Asia Minor, Transcaucasia, Iran, and the highlands of Turkmenistan (Bolton et al., 1972, Lesins, 1976, Lesins & Lesins, 1979, and Vavilov, 1951). European colonists were the first to introduce alfalfa to North America in the state of Georgia in 1736, but this and subsequent attempts at reintroduction were unsuccessful mainly due to poor soil conditions in that region (Russelle, 2001 and Stewart, 1926). During the Gold Rush in the early 1850s, Spanish cultivars imported from South America were first introduced in California and it was the introduction of the "Chilean clover" that led to the alfalfa revolution in the United States (Russelle, 2001 and Stewart, 1926). Due to the dry, calcareous soils in addition to good drainage, it was not long before alfalfa became the leading perennial forage legume opted by farmers and ranchers and was soon progressively incorporated in the western United States agriculture.

Typically, a well-maintained alfalfa stand remains productive for approximately 5 years. Although in some areas of the world, alfalfa may be allowed to remain in the field for as long as 20 years (Summers, 1998). Such longevity in the field coupled with the lush, dense foliage of alfalfa offers a relatively stable and suitable habitat for exploitation by a diverse array of organisms (Brown & Fick, 1986). While most of these organisms are neither harmful nor beneficial to the crop, some are destructive pests and can cause significant economic damage in well-managed fields. In the United States alone, an estimated $400 million in annual losses is caused by pathogens and nematodes, followed by $260 million by arthropods (Manglitz & Ratcliffe, 1988, and Leath et al., 1988). Some of the most destructive pests include alfalfa weevil, *H. postica* Gyllenhall (Coleoptera: Curculionidae), Egyptian alfalfa weevil, *Hypera brunneipennis* Boheman (Coleoptera: Curculionidae), alfalfa root weevil, *Sitona discoideus* Gyllenhall (Coleoptera: Curculionidae), potato leafhopper, *Empoasca fabae* Harris (Hemiptera: Cicadellidae), spotted alfalfa aphid, *Therioaphis maculata* Buckton (Hemiptera: Aphididae), pea aphid, *Acyrthosiphon pisum* Harris (Hemiptera: Aphididae), blue alfalfa aphid, *Acyrthosiphon kondoi* Shinji (Hemiptera: Aphididae), three-cornered alfalfa hopper, *Spissistilus festinus* Say (Hemiptera: Membracidae), meadow spittlebug, *Philaneus spumarius* Linnaeus (Hemiptera: Aphrophoridae), armyworms, *Spodoptera* spp. (Lepidoptera: Noctuidae), webworms, *Loxostege* spp. and *Achyra* spp. (Lepidoptera: Pyralidae), and mirids, especially *Lygus hesperus* Knight, and *Lygus elisus* Van Duzee (Flanders & Radcliffe, 2000 and Modarres Awal, 1997).

With the current advances in molecular technology, breeding plants for resistance against pests and diseases is gaining much attention in the field of crop management with billions of dollars being spent each year on research and development programs. Many plant cultivars with multiple pest resistance are now commercially available and are being increasingly incorporated in today's global agriculture, and alfalfa is no exception.

The most successful development of alfalfa cultivars resistance to insect pests has been with the aphids and through the years, numerous cultivars with resistance to pea aphid, blue alfalfa aphid, and spotted alfalfa aphid have been released (Nielson & Lehman, 1980, Manglitz & Radcliffe, 1988, and Sorensen et al., 1988). However, this has not been the case with the alfalfa weevil, which is the most economically damaging insect pest of alfalfa in the United States (Blodgett et al., 2000). Breeding alfalfa cultivars for resistance against alfalfa weevil has been one of the most challenging in the history of alfalfa breeding programs. In 1969, USDA released the alfalfa cultivar 'Team' which has partial resistance to alfalfa weevil (Flanders & Radcliffe, 2000). Although tolerant cultivars such as 'Team' have been made available to producers, they rarely provide adequate protection against alfalfa weevil, especially the larval infestations which inflict the most damage (Blodgett et al., 2000).

The three commercially available alfalfa cultivars present at our field site were ‘Cimarron SR’, ‘HayGrazer’, and ‘Shaw’. According to Cimarron USA, which is an alfalfa breeding company, ‘Cimarron SR’ and ‘HayGrazer’ cultivars possess a unique tolerance against alfalfa weevil and are capable of reducing weevil damage by 50% . The level of tolerance in these cultivars also allows for a delay in the need for spraying by 7 to 10 days and reduces pesticide application by 50%. ‘Shaw’ is a dryland cultivar with high yields and no current tolerance ratings against insect pests have been released by Montana State University, Bozeman.

Wireworms

“Wireworm” is the common name for the subterranean larval stage of click beetles (Coleoptera: Elateridae) which can inflict considerable damage to crops. Wireworms are found throughout the world and there are 965 known species of elaterids occurring in North America (Marske & Ivie, 2003). Although the adults are phytophagous, they rarely cause significant economic damage. However, the larvae are omnivorous and are destructive to a variety of agricultural crops including corn, sorghum, small grains, tobacco, potato, and various vegetables (Kuhar et al., 2009). Low numbers of wireworm (less than 100,000 per hectare) can inflict considerable economic losses (Parker & Howard, 2001). Crop growers experience 5 to 25% in annual yield losses in North America alone (Jansson & Seal, 1994).

Wireworms are known to overwinter in the soil either as larvae or adults. They are fairly long lived insects and depending on the species and environmental conditions, a particular generation may take anywhere from two to five years to complete its life cycle from eggs to adults (Parker & Howard, 2001). Wireworms spend the majority of their life as larvae in the soil feeding on germinating seeds, plants roots, and other insects but all stages may be present simultaneously throughout the growing season. The development rate of the larval stage is heavily influenced by food quality, temperature, and soil moisture (Parker & Howard, 2001). Because of this long life cycle, wireworms can cause high crop losses and are becoming an increasing problem to crop producers.

Carbon dioxide and heat produced by seeds during germination attract wireworms. Wireworms primarily feed on the seed germ reducing the likelihood of seeds germinating or cause the production of less vigorous seedlings. Roots of seedlings that germinate are also fed on by wireworms causing the seedlings to wilt and die. Crops are more prone to wireworm damage during the spring season when the temperature is much cooler and there is higher moisture in the soil. With increasing soil temperatures and decreasing soil moisture, the soil becomes less conducive for wireworms and they tend to move deeper into the soil.

Wireworms can be problematic to detect and study. Due to their soil-dwelling nature and below-ground feeding habits, symptoms of wireworm infestation (i.e., weak or wilting plants and reduced seed germination) are not noticeable before planting which leads to difficulty for the effective implementation of controlling and sampling measures (Lindroth & Clark, 2009). The larvae of many soil dwelling elaterids are difficult-toimpossible to identify with certainty because many species are undescribed, and those that are known have so much intraspecific variability that they overlap in morphology with related species (Riley & Keaster, 1981 and Staudacher et al., 2011). Because elaterids are long-lived, typically spending two to five years in the soil before completing their life cycle, rearing and breeding programs can be time consuming and costly.

OBJECTIVES

The research presented here had three sets of objectives. The first set of objectives explored the effects of three summer fallow weed management practices (sheep grazing, mechanical/ tillage, and chemical herbicide) incorporated in a three-year rotation on arthropod abundance in two different sets of crops: a pea (*Pisum sativum* L.) interseeded with hay barley (*Hordeum vulgare* L.) and spring wheat (*Triticum aestivum* L.). Arthropod abundance was compared among 1) the spring wheat plots under the three management practices with the rotational treatments (continuous spring wheat and rotational spring wheat), 2) the pea/hay barley plots under the different weed management schemes, and 3) fallow plots under the three management schemes. The second set of objectives examined arthropod abundance in another set of plots (no rotation or weed management schemes) planted with three alfalfa cultivars (Cimarron SR, HayGrazer, and Shaw). For both sets of objectives, we sampled arthropods using 1) sweep nets to compare the abundances of the most common arthropod orders and families (as well as a few abundant species and genera) and 2) baited traps to compare the abundance of wireworm (Coleoptera: Elateridae) within the different management treatments.

MATERIALS AND METHODS

Study Site and Treatments

Field work was conducted in the summers of 2010-2011 at Montana State University's Fort Ellis Experimental Station approximately 6.5 km east of Bozeman, Gallatin Co., Montana (N 45° 40' N, 111° 2' W, elevation: 1468 m). The site consisted of forty-five 0.14 ha plots (Fig. 1). The years in which rotations were applied to each plot are given in Table 2.

Between 2004 and 2008, the site was planted with wheat (cv. Vida) consisting of three cropping sequences (continuous spring wheat, spring wheat-fallow, and winter wheat-fallow) in a randomized complete split-plot design and summer fallow management treatments (grazed, chemical, and tillage) were applied to the main plots. Before 2004, the site was managed for ten years as perennial grass pasture consisting a mixture of smooth brome (*Bromus inermis* Leyss.), intermediate wheatgrass (*Thinopyrum intermedium* (Host) Barkworth & D.R. Dewy), and Canada bluegrass (*Poa compressa* L.) (Sainju et al.2011).

In this study, the summer fallow management treatments (grazed, chemical, and tillage) applied to the main plots from 2004-2008 were continued through 2011. Main plots were divided into five, 0.14 ha subplots with cropping system treatments applied to sub-plots and replicated three times. Subplots were assigned based on the previous cropping system treatments and randomization. In each main plot, three of the subplots were randomly assigned to each phase of a three-year rotation of spring wheat, followed by an annual forage consisting of a mixture of barley (cv. Hays) and field pea (cv. Arvika), followed by summer fallow. The other two subplots were grown with continuous alfalfa and spring wheat. The continuous spring wheat subplots remained the same as in the previous study started in 2004. Table 1 shows the complete study site design with the assigned treatments and cropping system for 2009-2011.

Figure 1: Aerial view of Fort Ellis research plots.

Table 1: Allocation of treatments and cropping system for 2009-2011.

PLOT	100'S	200'S	300'S
01	Mech. summer fallow 3 year rotation 2009 summer fallow 2010 spring wheat 2011 pea/hay barley	Chem. summer fallow 3 year rotation 2009 summer fallow 2010 spring wheat 2011 pea/hay barley	Grazed summer fallow 3 year rotation 2009 summer fallow 2010 spring wheat 2011 pea/hay barley
02	Mech. summer fallow 3 year rotation 2009 pea/hay barley 2010 summer fallow 2011 spring wheat	Chem. summer fallow 3 year rotation 2009 pea/hay barley 2010 summer fallow 2011 spring wheat	Grazed summer fallow 3 year rotation 2009 pea/hay barley 2010 summer fallow 2011 spring wheat
03	Mech. summer fallow 3 year rotation 2009 spring wheat 2010 pea/hay barley 2011 summer fallow	Chem. summer fallow 3 year rotation 2009 spring wheat 2010 pea/hay barley 2011 summer fallow	Grazed summer fallow 3 year rotation 2009 spring wheat 2010 pea/hay barley 2011 summer fallow

Table 1 Continued

04	Alfalfa (Cimarron SR)	Alfalfa (Shaw)	Alfalfa (HayGrazer)
05	Spring wheat continuous	Spring wheat continuous	Spring wheat continuous
06	Grazed summer fallow 3 year rotation 2009 summer fallow 2010 spring wheat 2011 pea/hay barley	Mech. summer fallow 3 year rotation 2009 summer fallow 2010 spring wheat 2011 pea/hay barley	Chem. summer fallow 3 year rotation 2009 summer fallow 2010 spring wheat 2011 pea/hay barley
07	Alfalfa (HayGrazer)	Alfalfa (Cimarron SR)	Alfalfa (Shaw)
08	Spring wheat continuous	Spring wheat continuous	Spring wheat continuous
09	Grazed summer fallow 3 year rotation 2009 pea/hay barley 2010 summer fallow 2011 spring wheat	Mech. summer fallow 3 year rotation 2009 pea/hay barley 2010 summer fallow 2011 spring wheat	Chem. summer fallow 3 year rotation 2009 pea/hay barley 2010 summer fallow 2011 spring wheat
10	Grazed summer fallow 3 year rotation 2009 spring wheat 2010 pea/hay barley 2011 summer fallow	Mech. summer fallow 3 year rotation 2009 spring wheat 2010 pea/hay barley 2011 summer fallow	Chem. summer fallow 3 year rotation 2009 spring wheat 2010 pea/hay barley 2011 summer fallow
11	Chem. summer fallow 3 year rotation 2009 summer fallow 2010 spring wheat 2011 pea/hay barley	Grazed summer fallow 3 year rotation 2009 summer fallow 2010 spring wheat 2011 pea/hay barley	Mech. summer fallow 3 year rotation 2009 summer fallow 2010 spring wheat 2011 pea/hay barley
12	Chem. summer fallow 3 year rotation 2009 pea/hay barley 2010 summer fallow 2011 spring wheat	Grazed summer fallow 3 year rotation 2009 pea/hay barley 2010 summer fallow 2011 spring wheat	Mech. summer fallow 3 year rotation 2009 pea/hay barley 2010 summer fallow 2011 spring wheat
13	Alfalfa (Shaw)	Alfalfa (HayGrazer)	Alfalfa (Cimarron SR)
14	Spring wheat continuous	Spring wheat continuous	Spring wheat continuous
15	Chem. summer fallow 3 year rotation 2009 spring wheat 2010 pea/hay barley 2011 summer fallow	Grazed summer fallow 3 year rotation 2009 spring wheat 2010 pea/hay barley 2011 summer fallow	Mech. summer fallow 3 year rotation 2009 spring wheat 2010 pea/hay barley 2011 summer fallow

The 9 alfalfa subplots were in a split-plot experimental design consisting of 3 replicates with the main plots split among 3 cultivars (Cimarron SR, Shaw and Hay Grazer). The alfalfa plots were maintained without any herbicide or insecticide applications throughout the 3-year study, with the exception of one-time application of Pursuit® (BASF Co.) at 280 a.i. ha^{-1} (grams of active ingredients per hectare) and R-11® (Wilbur-Ellis Co.) surfactant at 2.5 ml/L in July 2009.

Crop and Summer Fallow Management

Within each fallow management treatment, different agronomic practices were used for pre-planting and post-harvest weed and residue management, as well as weed control during fallow years (Table 2). Prior to planting, all treatments were fertilized and tilled. Crops were fertilized based on residual nitrogen, projected yield goals, and crop type (Table 2). Residual soil nitrogen was sampled in the fall (Mid-October) of each year. Five soil samples (4 cm in diameter and to a depth of 60 cm) were taken per sub-plot, homogenized, and analyzed. Fertilizer was applied at seeding as granular urea using a Gandy spreader. Chemical treatment plots received herbicides application (glyphosate at 416 g a.i. ha^{-1} and dicamba at 281 g a.i. ha^{-1}) zero to four days before seeding. In the grazed treatment, one to two weeks of sheep grazing was used for pre-planting weed control but was not used in 2009. Pre-planting stocking rates (mean of 484 sheep days ha^{-1}) varied slightly depending of weed pressure and precipitation. In mechanical tillage treatments, no additional pre-plant management was applied.

Planting dates were 19 May 2009, 17 May 2010, and 16 May 2011. All crops were planted at 15-cm row spacing at the seeding rates listed in Table 3. Post-emergent herbicides were applied in rotational and continuous spring wheat. In the forage crop phase of the three-year rotation, only sub-plots that were in the spring wheat rotation phase were treated with post-emergent herbicides and these applications were determined by weed identity, pressure, and management treatment. In the first year of the study, no in-crop herbicides were applied. In 2010, all plots were sprayed with a tank-mixture of dicamba and pinoxaden (140 g a.i. ha^{-1} + 30 g a.i. ha^{-1}) four weeks after seeding. In 2011, no herbicides were applied in grazed and mechanically managed spring wheat in the three-year rotation. In-crop herbicides were applied in chemically managed spring wheat in the rotational and continuous spring wheat. In chemically managed spring wheat in the three-year rotation phase, weeds were controlled with dicamba (140 g a.i. ha^{-1}) three weeks after seeding and pyrasulfotole + bromoxynil (41 g a.i. ha^{-1} + 230 g a.i. ha^{-1}) applied four weeks after seeding. In the continuous spring wheat, grassy weeds were controlled with pinoxaden (74 g a.i. ha^{-1}) applied six weeks after seeding.

Post-harvest crop residue and weed management also differed across management treatments and previous crop (Table 2). In grazed treatments, sheep grazing was utilized after straw was removed for residue reduction and incorporation. Post-harvest grazing in spring wheat was not applied in the first year of the experiment. In chemical and mechanical treatments, spring wheat straw was windrowed and bailed following harvest.

In the forage crop phase of the three-year rotation, harvest and post-harvest practices differed among the three management treatments. In the chemical and mechanical treatments, the forage crop was swathed, windrowed, baled, and removed. Chemical and mechanical treatments received a post-harvest (mid-August) application of glyphosate (416 g a.i. ha^{-1}) in 2009. In the mechanical treatments, residues were incorporated with an EZ-off set disk. In grazed treatments, the forage crop was windrowed and used for sheep-forage in situ. In 2009, post-harvest grazing differed slightly as intensive rain fell on windrowed crop and resulting moldy, unpalatable forage. The forage crop was baled and removed, sheep were grazed on stubble. In subsequent years, sheep were kept on plots for two to three weeks until forage was exhausted.

The largest differences among sub-plots occurred during the summer fallow phase of the rotation treatments (Table 2). Summer fallow weed control in the plots allocated to mechanical control was managed by means of tillage. A John Deere 740® tractor pulling a John Deere 100® toolbar equipped with cultivators was used to till soil to a depth of approximately 15 cm. In the grazed treatment, summer fallow phase plots were grazed until weed biomass was less than 5% ground cover (approximately 47 kg ha^{-1}) based on visual assessment. Variable sheep stocking rate, intensity, and duration were employed for each of the fallow phase plots based on weed biomass and precipitation. In previous fieldwork at the site (P. Hatfield, personal communication), it was found that young green weeds are consumed before wheat stubble. Therefore, we were certain that the proper amount of stubble cover to conform to USDA-NRCS soil cover regulations for erosion prevention and Farm Program participation was maintained. All fallow management treatments were applied every four to six weeks from June to September depending on weed abundance.

Table 2: Description of management treatments within cropping systems. Exceptions are noted with numeric subscripts and detailed below. Abbreviations: SR=seeding rate in kg seed ha^{-1}, YG=yield goal in Mg ha^{-1}, TN=target nitrogen fertility in kg ha^{-1}

Cropping Systems	Phase	Fallow management	Pre-plant agronomic practices	Post-harvest agronomic practices
Three-year rotation	Forage (pea-barley) SR: 50.5_{barley} 112.1_{pea} YG: 8.97 TN: 134.5	Chemical	Glyphosate and dicamba applied-fertilized-shallow tillage	Forage bailed and removed$_1$
		Mechanical	Fertilized-shallow tillage	Forage bailed and removed$_1$- -residues incorporated with tillage
		Graze	Grazing$_2$: 549-586 sheep days ha^{-1} fertilized-shallow tillage	Swath-grazed$_3$: 1026 to 1281 sheep days ha^{-1}
Wheat-fallow & Three-year rotation	Fallow: treatments applied every four to six weeks	Chemical	Herbicides (glyphosate and dicamba tank mix applied at 416 g a.i.ha^{-1} and 281g a.i.ha^{-1}, respectively)	
		Mechanical	Tilled with a John Deere 100 field cultivator fitted with 15 cm wide sweeps	
		Graze	Grazed: 234 to 498 sheep days ha^{-1}	
Wheat-fallow Three-year rotation & Continuous spring wheat	Spring wheat SR: 89.7 YG:$4.8_{continuous}$ $6.1_{rotations}$ TN:$202_{continuous}$ $252_{rotations}$	Chemical	Glyphosate and dicamba applied-fertilized-shallow tillage	Straw bailed and removed- residues incorporated with tillage
		Mechanical	Fertilized-shallow tillage	Straw removed- residues incorporated with tillage
		Graze	Grazing$_2$: 176-344 sheep days ha^{-1} -fertilized-shallow tillage	Straw removed-Grazed residues$_2$ 659-806 sheep days ha^{-1}

1. post-harvest application of glyphosate (416 g a.i. ha^{-1}) in 2009
2. Treatment not applied in 2009
3. In 2009, forage rotted in field, was removed, and sheep grazed residues

Above-ground Arthropod Sampling and Analysis

We used two methods to sample arthropods in each plot: 1) sweep netting to sample the above-ground arthropods and 2) baited traps in the soil, used specifically for larval wireworms (Coleoptera: Elateridae). Sweep samples consisted of 50 sweeps taken along a transect that ran lengthwise through the center of each plot. Each sweep was done with a 45-cm diameter net traversed at 180° arc parallel to the ground and through the center of the vegetation. In bare plots, each sweep was done approximately 10 cm above the ground. Because the height of the vegetation varied among plots, the height of the sweep nets during sampling also varied among plots and across dates.

Sweep samples were taken in each of the 45 plots 9 times in 2010 (14 and 28 June, 8, 19 and 30 July, 9, 18 and 26 August, and 3 September) and seven times in 2011 (21 June, 1, 18 and 28 July, and 6, 17 and 27 August). To minimize the effects of variation in weather and sampling bias associated with sweeping technique (Larson et al. 1999 and O'Neill et al. 2003), samples were taken by the same person only on clear, warm days with low wind speeds. To reduce the influence of time of day on the results, the sequence of sampling of plots was changed each sampling date by alternating between different plots.

All samples were transported to the laboratory in a cooler and immediately frozen. Later, samples were thawed, arthropods were separated from plant debris, and then returned to the freezer. Arthropods in the families listed in Table 3 were counted and identified; the families were grouped into three ecologically functional and economically relevant categories (pests, pollinators, and natural enemies). In addition, a subset of other insects was identified to genus or species (see Results).

The total arthropod counts, and counts of specific arthropod orders and insect families among treatments/cultivars within each habitat category (alfalfa, pea/hay barley and summer fallow) were analyzed using a repeated measures split-split-plot ANOVA with management treatments/cultivars as a fixed main-plot factor, block as a random main-plot factor, and interaction between management treatments/cultivars and sampling dates as the repeated factor (i.e. split-split plot factor). The same was done for spring wheat with the addition of a second plot factor (rotational treatments) and the interaction between management and rotational treatments as the split-plot factors. Arthropod count data were square-root transformed before being analyzed. We tested the hypothesis that abundance of orders, families, genera, and species of selected arthropods differed among management and rotational treatments/cultivars of each habitat. To test for differences in abundance among treatments/cultivars within habitat classes, we used Least Significant Difference (LSD) test, the null hypothesis being that members of a taxon should be equally distributed among plots within a treatment/cultivar of the same habitat class. All the above analyses were done using R statistical software (version 2.15.3; R Development Core Team).

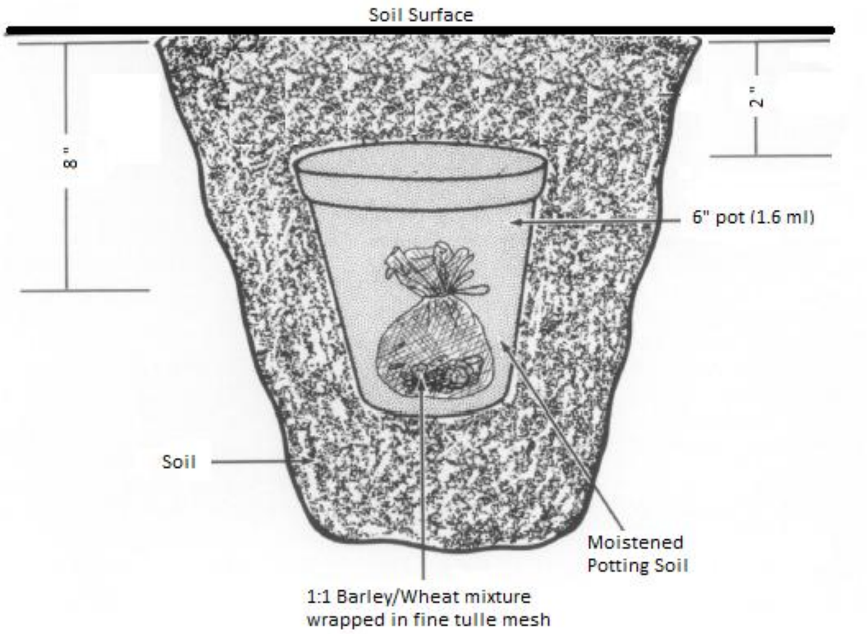
Table 3: Important economical and ecologically functional groups.

Herbivores	Natural Enemies	Pollinators
Acrididae	Reduviidae	Lepidoptera (adults)
Aphididae	Nabidae	Syrphidae
Cicadellidae	Anthocoridae	Andrenidae
Miridae	Chrysopidae	Apidae
Chrysomelidae	Coccinellidae	Colletidae
Meloidae (adults)	Araneae	Halictidae
Curculionidae	Asilidae	Megachilidae
Lepidoptera (larvae)	Ichneumonoidea	
	Chalcidoidea	
	Sphecidae	

Wireworm Sampling and Analysis

Wireworms were sampled using the method of Kirfman et al. (1986) with traps baited with a 1:1 ratio of barley:spring wheat seeds (60 ml of each seed type) wrapped in fine cloth mesh and soaked in water for 24 hours before being placed in the center of perforated 1.08 L canisters filled with soilless potting mix; each canister had 31 holes of 5 mm diameter (30 on the side and one on the bottom). All the canisters packed with seeds were soaked with water for 24 hours before being placed in approximately 20-cm deep holes in the ground. Three canisters were placed along a longitudinal transect (equally spaced) in the center of each of the 45 plots. All the canisters were retrieved from the field after 14 days and stored in cold storage at 4°C before being sorted for wireworms. Wireworms were extracted by first removing the contents of the canisters and then sorting through the potting mix as well as the seedlings wrapped in fine mesh by hand. Wireworms found were placed in vials filled with 95% ethanol and labeled with the date, plot, and location within the plot. We sampled 3 times during the summer of 2010 and 8 times during the summer of 2011. Because wireworms are difficult to identify to species using standard techniques, with the help from Dr. Kevin Wanner's and Dr. Mike Ivie's labs (Montana State University), they were identified using DNA barcoding techniques. We tested the hypothesis that the total wireworm abundance differed among treatments or crops using Kruskal-Wallis one-way ANOVA followed by Student-Newman-Keuls tests (for equal sample sizes among treatment/crop) or Dunn's tests (for unequal sample sizes among treatment/crop) for multiple comparisons (α = 0.05). We also examined which wireworm species were most closely associated with each treatment or crop as well as their abundance using the same procedure.

Figure 2: Lateral view of in situ wireworm trap. Modified from Kirfman et al. (1996)



RESULTS

Overall Arthropod Abundance

During the study, arthropods from 15 orders (13 from the class Insecta and 2 from the Arachnida) were identified in sweep samples, 181,663 in 2010 and 134,850 in 2011. The eleven least abundant orders (Orthoptera, Lepidoptera, Trichoptera, Neuroptera, Ephemeroptera, Odonata, Plecoptera, Psocoptera, Dermaptera, Araneae, and Opiliones) represented less than 2% of the total arthropod count in each year.

Among the arthropod orders, Hemiptera was the most abundant both years (Fig. 3). Coleoptera showed the greatest proportional change in abundance between years. Arthropods lumped together in the category “Others” in Fig. 4 were mostly from the order Diptera, which were not identified to family. The four most common arthropod families included three Hemiptera and one Coleoptera (Fig. 4). Curculionidae (mostly alfalfa weevil larvae, *Hypera postica*), which was the fourth most common insect family in 2010, was the most common the following year, replacing Miridae.

In both years, the alfalfa plot had the highest mean counts of arthropods; in 2010, the mean arthropod abundance in alfalfa plots was more than twice as high compared to a pea/hay barley plot which was ranked second (Fig. 5). Unlike the alfalfa and pea/hay barley plots which experienced a decrease in their average total arthropod numbers from the previous year, spring wheat and summer fallow plots saw an increase in their average total arthropod abundance. Summer fallow plots in both years always had the lowest number of arthropods. In all of the 2010 (except in the first) and 2011 sampling dates, the fewest numbers of arthropods were collected from the summer fallow plots (Fig. 8).

Unlike most arthropods that experienced a decline in their numbers by the end of the 2010 sampling season, cicadellids in the pea/hay barley plots kept increasing and on the last sampling date they were more than three times the abundance compared with their counterparts in the spring wheat plots (Fig. 10). Even the coccinellids in the spring wheat plots increased in their numbers as the summer in 2010 progressed. The only arthropods that increased in numbers by the end of the 2011 sampling season were the nabids in the spring wheat plots. There were 196 nabids in the spring wheat plots compared with less than 19 in all the other plot types combined on the last 2011 sampling date (August 27th).

Arthropods in Spring Wheat Plots (Both Rotational and Continuous Spring Wheat)

In both years, Hemiptera made up the majority of arthropods and Diptera was the second most abundant arthropod order. Hymenoptera, which was ranked third in 2010, was replaced by Coleoptera in 2011 (Fig. 6). In the spring wheat plots, the trend was similar in both years with Miridae, Cicadellidae, and Aphididae ranked as the major insect families (Fig. 7). There were no consistent temporal trends in overall arthropod abundance each year, primarily because increases in the abundance of Hemiptera were offset by lower numbers of Diptera late in the summer (Fig. 9).

The results of the repeated-measure analysis of variance indicate that there were no significant treatment effects (chemical, graze, and mechanical) on the abundance of all arthropods in either year (Table 4). However, in both years there was a significant rotational effect due to higher numbers of arthropods in three-year rotational spring wheat compared to continuous spring wheat (Table 4 and 5, Fig. 11). Only in 2010 was there also a significant treatment by rotational interaction. In 2010, total arthropod abundance was the highest in the grazed and mechanically-treated rotational spring wheat (Table 4 and 5). Only in 2011 was there a significant treatment by date effect as arthropods increased in abundance during the summer in the rotational plots (Table 4 and 5, Fig. 11).

Among the most abundant arthropod taxa, we also found significant treatment effects for Miridae (2010), *Trigonotylus* spp. (2010), Piesmatidae (2010), Lygaeidae (2011), *Lygus* spp. (2011), Nabidae (2011), and Formicidae (2011). Significant rotational effects (but not treatment by rotational effects) were observed for Hemiptera (2011), Miridae (both years), *Trigonotylus* (both years), Nabidae (2010), Cicadellidae (2011), Piesmatidae (2010), Chalcidoidea (2011), and Cocinellidae (both years); each of these taxa was more abundant in the rotational spring wheat than in the continuous spring wheat plots (Table 4 and 5, Fig. 11 and 12).

Treatment by rotational interactions were significant for several taxa, but the patterns of differences varied among taxa. Hemiptera (2010) were more abundant in grazed rotational plots than in the mechanical continuous spring wheat. Cicadellidae (2010) were more abundant in grazed and mechanical rotational plots than in all of the other plot types. *Lygus* spp. (2011) were more abundant in grazed rotational plots than in the chemical and mechanical rotational spring wheat. Nabids (2011) were more abundant in grazed rotational plots than in chemical continuous spring wheat. Aphids (2011) were more abundant in grazed rotational plots than in all of the other plot types. The most consistent pattern is that these insects were generally most abundant in the grazed rotational plots (Table 4 and 5, Fig. 11 and 12).

Arthropods in Pea/Hay Barley Plots

In both years, Hemiptera was the most abundant order, with Diptera second and Coleoptera third (Fig. 6). Aphididae, which was ranked third in 2010, dominated the pea hay barley plots in 2011, replacing Cicadellidae as the most abundant family (Fig. 7).

The results of the repeated-measure analysis of variance, indicate that there was a significant treatment effect on the abundance of all arthropods in 2010 (p = 0.013), but not in 2011 (p = 0.426) (Table 6). The plots under the grazed treatment had the highest arthropod abundance in 2010 (Table 6 and 7, Fig. 13).

Among the arthropod taxa, there was a significant treatment effect for Hemiptera (2010), Miridae (2010), *Trigonotylus* spp. (2010), Hymenoptera (2010), Chalcidoidea (2010), Diptera (2010), Curculionidae (2010), Arachnida (both years), and Lepidoptera (2011); each of these taxa was most abundant in the grazed plots than in the chemical and mechanical plots. *Sitona discoideus* (2010), however, was least abundant in the grazed plots. (Table 6 and 7, Fig. 13 and 14).

Treatment by date interactions were significant for several taxa, but the patterns of differences varied among taxa. Aphididae (2010), Lygaeidae (2011), *Lygus* spp. (2011), Nabidae (2011), were more abundant in grazed plots than in the chemical and mechanical plots. Formicidae (2010) was most abundant in chemical and grazed plots.

Trigonotylus spp. (2011) was most abundant mechanical plots than in chemical and grazed plots. Coleoptera (both years), Curculionidae (2011), and *Sitona discoideus* (2011) were most abundant in chemical and mechanical plots (Table 6 and 7, Fig. 13 and 14).

Arthropods in Summer Fallow Plots

In both years, Hemiptera made up the majority of arthropods and Diptera was the second most abundant arthropod order, followed by Hymenoptera third (Fig. 6). Lygaeidae, which never consisted of >1.4% of arthropods in the plots with crops, was relatively abundant on fallow plots (8.5% in 2010 and 10.2% in 2011) and was the third most common insect family behind Cicadellidae and Miridae for both years in the summer fallow plots (Fig. 7). No consistent temporal trends were obvious in each year.

The results of the repeated-measure analysis of variance, indicate that there was a significant treatment effects on the abundance of all arthropods in 2010 ($p < 0.001$) and 2011 ($p = 0.013$) (Table 8). Most arthropods were at their highest abundances in the chemically and grazed managed fallow plots, and the lowest in the mechanically managed fallow plots in both 2010 and 2011 (Table 8 and 9, Fig. 15 and 16).

Arthropods in Alfalfa Plots

Hemiptera were the most common arthropods in 2010, but in 2011 they were replaced by Coleoptera (Fig. 6), mostly *Hypera postica* larvae. Due to the almost threefold increase compared with 2010, Curculionidae (69.1%) switched ranks with Aphididae as the most common family in alfalfa in 2011 (Fig. 7).

The average total arthropod abundance of an alfalfa plot was always the highest in late June and early July each year (Fig. 8), primarily to due high numbers of Hemiptera, Coleoptera, and Diptera. There was a slight increase in numbers of arthropods during August of each year, due to higher numbers of Hemiptera and Diptera.

Arthropod abundance was not statistically different among the three alfalfa cultivars for 2010 (p = 0.072) and 2011 (p = 0.325) (Table 10). During the 2010 sampling season, aphids were always most abundant (except for the 5th sampling date; July 30th) in alfalfa plots planted with the Hay Grazer cultivar and ichneumonids were more common in the Cimarron SR and Hay Grazer cultivar plots (Table 10 and 11, Fig. 18). Ants (Formicidae) were found to be most common in the Hay Grazer alfalfa cultivar plots through all the 2010 sampling dates (Table 10 and 11, Fig. 18). In 2011, however, not a single arthropod taxon was found to be statistically more associated with any of the alfalfa cultivars (Table 10).

Wireworm Abundance

In 2010, 97 wireworms of seven species (*Aeolus mellillus* Say, *Dalopius* sp., *Hypnoidus leei* Stibick, *Limonius infuscatus* Motschulsky, *Athous sierrae varius* Lane, *Hemicrepidius* sp. nr. *carbonatus*, and *Selatosomus aeripennis* Kirby) were collected in the baited traps and 15 click beetles of six species (*A. mellillus, Agriotes criddlei* Van Dyke, *Dalopius spretus* Brown, *Hemicrepidius* sp. nr. *carbonatus, Hadromorphus* *glaucus* Brown, and *Pseudanostirus* sp.) were collected through sweep netting. In 2011, with the additional five sampling (bait trapping) dates, 291 wireworms were collected with the addition of two species (*Agriotes* sp. and *Melanotus longulus oregonensis* LeConte) and 10 click beetles of three species (*A. criddlei, D. spretus, H. glaucus*) were collected through sweep netting (Table 12). The majority (> 90%) of wireworms collected in both years were *A. mellillus*, *Dalopius* sp., and *H. leei* (Fig. 19).

In combined data across each summer, continuous spring wheat plots had significantly higher number of wireworms than alfalfa and rotational plots in 2010 (*p* = < 0.001) and in 2011 (*p* = < 0.001; Table 13 and Fig. 20). When the plots that were under the three-year rotational scheme were divided further with respect to their rotational phase (fallow, pea/hay barley, and rotational spring wheat) and compared against the continuous spring wheat and alfalfa plots, wireworms were significantly more abundant in continuous spring wheat plots in both 2010 (*p* = < 0.001) and 2011 (*p* = < 0.001; Table 14 and Fig. 21). Results showed that there was no significant difference in the numbers of wireworms present among the three alfalfa cultivars in 2010 (*p* = 0.065) and 2011 (*p* = 0.083; Table 15 and Fig. 22). There were also no significant differences in the numbers of wireworms present among the rotational phase plots managed under the chemical, graze, and mechanical treatments in 2010 (*p* = 0.221) and 2011 (*p* = 0.051; Table 16 and Fig. 23).

We also did separate analyses on the three most abundant species of wireworm. Of those, *A. mellillus* was significantly more abundant in continuous spring wheat plots in 2010 (*p* = < 0.001) and 2011 (*p* = < 0.001; Table 17 and Fig. 24). However, no significant differences were found for *Dalopius* sp. (Table 18 and Fig. 25), *H. leei* (Table 19 and Fig. 26), and the other wireworm species (Table 20 and Fig. 27).

Table 4: Results of repeated-measures analysis of variance on arthropod abundance in spring wheat plots (2010-2011). In 2010, d.f. = 2, 4 (treatment effects), d.f. = 1, 6 (rotational effects), d.f. = 2, 6 (treatment x rotational effects), d.f. = 16, 96 (treatment x date interactions), d.f. = 8, 96 (rotational x date interactions), d.f. = 16, 96 (treatment x rotational x date interactions); in 2011, d.f. = 2, 4 (treatment effects), d.f. = 1, 6 (rotational effects), d.f. = 2, 6 (treatment x rotational effects), d.f. = 12, 72 (treatment x date interactions), d.f. = 6, 72 (rotational x date interactions), d.f. = 12, 72 (treatment x rotational x date interactions).

		Treatment effects		Rotational effects		Treatment x rotational effects		Treatment x date interactions		Rotational x date interactions		Treatment x rotational x date interactions	
Year	Taxon	F	P	F	P	F	P	F	P	F	P	F	P
2010	All Arthropods	1.01	0.441	139.28	<0.001	10.85	0.010	0.40	0.980	2.74	0.009	0.66	0.828
	Orthoptera	1.96	0.255	3.00	0.134	14.46	0.005	1.02	0.444	1.65	0.120	0.76	0.723
	Acrididae	1.74	0.286	3.30	0.119	8.44	0.018	1.01	0.457	1.59	0.137	0.83	0.653
	Hemiptera	1.71	0.290	79.97	<0.001	8.41	0.018	0.40	0.980	4.42	<0.001	0.74	0.750
	Anthocoridae	0.85	0.491	5.21	0.063	1.96	0.221	1.15	0.320	1.49	0.173	0.76	0.729
	Lygaeidae	0.34	0.731	0.05	0.832	0.41	0.681	0.87	0.600	0.47	0.878	2.52	0.003
	Miridae	45.12	0.002	67.95	<0.001	2.36	0.175	0.59	0.887	5.71	<0.001	0.53	0.925
	Adelphocoris spp.	0.12	0.890	0.02	0.907	2.04	0.211	1.24	0.256	1.34	0.232	3.17	<0.001
	Lygus spp.	2.94	0.164	0.59	0.471	4.82	0.056	1.08	0.381	1.42	0.198	1.60	0.083
	Trigonotylus spp.	11.14	0.023	52.70	<0.001	1.33	0.332	0.78	0.701	6.63	<0.001	0.49	0.946
	Nabidae	2.32	0.215	29.04	0.002	0.02	0.984	0.78	0.704	7.48	<0.001	1.02	0.443
	Piesmatidae	20.80	0.008	17.76	0.006	3.10	0.119	2.70	0.001	5.34	<0.001	1.98	0.022
	Rhopalidae	6.07	0.061	2.02	0.205	3.19	0.114	3.36	<0.001	3.77	<0.001	3.80	<0.001
	Aphididae	0.31	0.751	0.76	0.416	1.07	0.402	1.11	0.354	12.80	<0.001	2.08	0.015

Table 4 Continued

	Cercopidae	0.20	0.826	1.79	0.230	2.91	0.131	0.62	0.863	0.77	0.632	1.23	0.260
	Cicadellidae	0.25	0.792	34.41	0.001	18.62	0.003	0.72	0.766	5.16	<0.001	0.63	0.853
	Hymenoptera	1.27	0.373	3.44	0.113	1.01	0.419	1.14	0.332	4.90	<0.001	0.71	0.782
	Chalcidoidea	0.51	0.638	5.40	0.059	1.13	0.383	1.31	0.209	8.46	<0.001	1.65	0.071
	Braconidae	0.18	0.845	2.13	0.195	0.09	0.912	0.76	0.722	1.12	0.355	0.74	0.745
	Ichneumonidae	0.31	0.747	7.31	0.035	4.27	0.070	0.55	0.912	2.91	0.006	2.61	0.002
	Formicidae	5.63	0.069	0.63	0.459	3.27	0.110	1.41	0.153	1.77	0.093	0.64	0.846
	Diptera	0.41	0.689	57.09	<0.001	10.55	0.011	0.50	0.940	3.35	0.002	0.96	0.504
	Lepidoptera	0.76	0.525	0.04	0.848	1.55	0.288	0.90	0.573	0.90	0.524	1.80	0.042
	Coleoptera	0.76	0.524	33.12	0.001	0.16	0.855	0.63	0.855	5.09	<0.001	0.41	0.977
	Chrysomelidae	0.15	0.864	0.82	0.402	2.07	0.207	0.84	0.633	0.29	0.967	0.91	0.556
	Coccinellidae	0.22	0.815	28.11	0.002	0.23	0.803	0.81	0.676	7.53	<0.001	0.38	0.985
	Curculionidae	0.71	0.545	1.60	0.252	0.10	0.911	0.79	0.689	0.73	0.666	0.61	0.867
	Hypera postica	1.38	0.350	0.65	0.452	0.10	0.907	1.60	0.084	0.94	0.488	0.37	0.986
	Sitona discoideus	0.53	0.627	0.02	0.886	0.97	0.431	0.86	0.612	1.10	0.368	0.42	0.975
	Arachnida	0.02	0.978	1.47	0.271	0.95	0.437	1.18	0.298	2.82	0.008	0.85	0.627
	Other Insects	0.35	0.722	2.45	0.169	2.99	0.125	1.29	0.219	0.67	0.720	0.43	0.972
2011	All Arthropods	0.54	0.620	37.79	<0.001	3.55	0.096	2.37	0.013	8.44	<0.001	1.15	0.337
	Orthoptera	4.23	0.103	0.07	0.801	0.30	0.755	1.89	0.050	0.41	0.872	1.65	0.098
	Acrididae	4.76	0.087	0.44	0.531	0.28	0.763	1.81	0.063	0.61	0.723	1.39	0.191
	Hemiptera	0.51	0.635	36.40	<0.001	1.27	0.347	2.42	0.011	12.23	<0.001	1.20	0.302

Table 4 Continued

Anthocoridae	2.91	0.166	0.17	0.693	0.94	0.440	1.47	0.156	0.65	0.694	1.61	0.108
Lygaeidae	28.12	0.004	1.44	0.275	1.32	0.336	2.55	0.007	2.76	0.018	3.07	0.002
Miridae	0.59	0.595	30.67	0.001	0.67	0.546	3.74	<0.001	21.54	<0.001	3.00	0.002
Adelphocoris spp.	5.88	0.064	18.44	0.005	0.75	0.511	2.31	0.015	5.50	<0.001	1.15	0.332
Lygus spp.	10.11	0.027	0.55	0.487	9.93	0.013	0.74	0.712	9.81	<0.001	1.02	0.444
Trigonotylus spp.	2.66	0.184	21.84	0.003	0.81	0.489	4.00	<0.001	29.10	<0.001	2.83	0.003
Nabidae	10.48	0.026	1.11	0.332	12.35	0.008	2.71	0.004	2.34	0.040	0.92	0.437
Piesmatidae	0.40	0.694	0.10	0.764	0.71	0.530	0.72	0.728	0.71	0.643	0.69	0.752
Rhopalidae	3.51	0.132	6.46	0.044	3.03	0.123	2.05	0.032	2.05	0.070	2.78	0.004
Aphididae	0.68	0.558	9.55	0.021	10.06	0.012	5.57	<0.001	5.12	<0.001	3.89	<0.001
Cercopidae	0.81	0.506	3.87	0.097	0.02	0.985	1.07	0.394	0.75	0.615	0.49	0.915
Cicadellidae	0.02	0.981	9.89	0.020	1.60	0.278	2.20	0.020	6.52	<0.001	1.58	0.117
Hymenoptera	4.67	0.090	4.63	0.075	0.59	0.585	3.66	<0.001	1.52	0.183	2.42	0.011
Chalcidoidea	5.92	0.064	50.61	<0.001	1.50	0.296	2.17	0.022	0.64	0.695	1.21	0.295
Braconidae	3.37	0.139	2.28	0.182	4.36	0.068	2.87	0.003	0.44	0.848	1.47	0.157
Ichneumonidae	0.05	0.950	0.58	0.476	1.21	0.361	1.32	0.229	1.29	0.274	1.04	0.425
Formicidae	25.13	0.005	20.96	0.004	0.20	0.823	2.05	0.032	1.36	0.243	2.29	0.016
Diptera	1.17	0.399	1.15	0.325	9.09	0.015	1.15	0.336	2.81	0.016	1.34	0.215
Lepidoptera	0.20	0.824	0.28	0.619	0.02	0.978	0.65	0.789	1.41	0.222	0.80	0.651
Coleoptera	2.77	0.176	11.02	0.016	4.21	0.072	6.13	<0.001	7.01	<0.001	4.07	<0.001
Chrysomelidae	0.84	0.495	3.22	0.123	0.70	0.532	1.01	0.446	1.14	0.349	1.01	0.447
Coccinellidae	0.12	0.889	26.22	0.002	2.06	0.209	7.22	<0.001	7.78	<0.001	3.78	<0.001

Table 4 Continued

Curculionidae	5.35	0.074	0.24	0.643	0.95	0.440	1.99	0.038	1.74	0.125	1.47	0.154
Hypera postica	2.34	0.212	0.42	0.540	1.39	0.320	0.74	0.708	0.15	0.988	0.62	0.821
Sitona discoideus	2.92	0.165	2.97	0.136	0.46	0.653	0.18	0.999	0.86	0.532	1.26	0.259
Arachnida	4.50	0.095	3.16	0.126	4.71	0.059	0.62	0.822	0.77	0.598	0.86	0.590
Other Insects	1.05	0.429	0.11	0.754	1.36	0.325	1.07	0.396	0.53	0.786	1.32	0.229

Table 5: Mean with standard error of arthropods collected from continuous and rotational spring wheat plots of the three treatments. Mean followed by different letter differ significantly from those of other treatments for the same year. (LSD test; α = 0.05). ^{a} represents treatment x rotational effects (p<0.05), $_{a}$ represents management effect (p<0.05) and * represents years with a significant rotational effect (p<0.05).

		Mean ± SE number collected (Spring Wheat)					
		Continuous Spring Wheat			Three Year Rotation		
Taxon	Year	Chemical	Graze	Mechanical	Chemical	Graze	Mechanical
All Arthropods	2010	2712 ± 148^{a}	2607 ± 79^{ab}	2439 ± 173^{a}	3269 ± 180^{bc}	4007 ± 136^{c}	3952 ±157^{c}
	2011*	2890 ± 148	2673 ± 100	2776 ± 67	3427 ± 62	4469 ± 217	4048 ± 600
Orthoptera	2010	27.0 ± 2.5	17.0 ± 3.1	14.3 ± 3.3	18.0 ± 4.0	40.0 ± 7.8	22.3 ± 6.8
	2011	23.0 ± 4.5	27.0 ± 7.8	11.3 ± 2.4	22.0 ± 3.5	21.0 ± 1.5	14.0 ± 4.4
Acrididae	2010	26.0 ± 2.7	16.3 ± 3.5	12.7 ± 4.5	18.0 ± 4.0	38.3 ± 7.1	21.7 ± 7.2
	2011	22.7 ± 4.2	26.7 ± 8.1	10.7 ± 2.2	20.7 ± 3.2	21.0 ± 1.5	12.3 ± 3.5

Table 5 Continued

Hemiptera	2010	1818 ± 108^{ab}	1773 ± 55^{ab}	1588 ± 114^{a}	2154 ± 55^{ab}	2714 ± 112^{b}	2751 ± 158^{ab}
	2011*	1923 ± 69	1923 ± 68	1986 ± 128	2607 ± 17	3294 ± 253	3225 ± 537
Anthocoridae	2010	0.7 ± 0.7	0.3 ± 0.3	0.3 ± 0.3	0.3 ± 0.3	2.0 ± 0.6	1.3 ± 0.7
	2011	1.7 ± 0.3	2.3 ± 1.9	2.3 ± 1.2	1.7 ± 0.7	5.0 ± 0.6	2.0 ± 1.2
Lygaeidae	2010	10.3 ± 2.4	10.7 ± 3.2	11.0 ± 1.7	7.3 ± 2.0	14.7 ± 6.3	11.7 ± 1.3
	2011	21.0 ± 3.5$_{a}$	60.0 ± 19.6$_{b}$	6.0 ± 1.5$_{a}$	14.0 ± 1.0$_{a}$	141.0 ± 68.6$_{b}$	13.0 ± 2.0$_{a}$
Miridae	2010*	649.3 ± 48.4$_{a}$	633.7 ± 13.3$_{a}$	591.3 ± 30.8$_{a}$	956 ± 72$_{b}$	1143 ± 104$_{bc}$	1297 ± 164$_{c}$
	2011*	607.7 ± 20.0	574.7 ± 40.4	623.7 ± 20.0	1167 ± 117	1017 ± 176	1573 ± 327
Adelphocoris spp.	2010	1.3 ± 0.3	0.0 ± 0.0	0.7 ± 0.3	0.3 ± 0.3	1.0 ± 1.0	0.3 ± 0.3
	2011*	15.0 ± 4.0	18.3 ± 2.2	5.7 ± 1.9	1.3 ± 0.3	9.0 ± 5.0	1.0 ± 0.6
Lygus spp.	2010	44.3 ± 14.0	26.3 ± 5.4	36.3 ± 17.7	13.3 ± 6.1	55.7 ± 7.3	19.3 ± 10.6
	2011	91.0 ± 21.7^{ab}	123.0 ± 14.6^{ab}	93.3 ± 23.4^{ab}	29.0 ± 0.6^{a}	224.0 ± 56.1^{b}	31.0 ± 8.2^{a}
Trigonotylus spp.	2010*	589.7 ± 38.0$_{a}$	598.3 ± 17.6$_{ab}$	542.7 ± 50.7$_{a}$	928 ± 77$_{bc}$	1067 ± 110$_{c}$	1249 ± 175$_{c}$
	2011*	485.0 ± 28.7	415.3 ± 39.9	509.0 ± 37.5	1109 ± 115	762 ± 228	1522 ± 319
Nabidae	2010*	71.0 ± 13.1	96.3 ± 14.3	82.0 ± 14.5	137.0 ± 24.5	161.3 ± 17.7	178.3 ± 14.5
	2011	335.7 ± 21.8^{a}	389.0 ± 43.0^{ab}	326.3 ± 10.4^{ab}	256.3 ± 38.4^{ab}	558.7 ± 62.9^{b}	315.0 ± 56.1^{ab}
Piesmatidae	2010*	10.0 ± 2.7$_{a}$	8.7 ± 0.9$_{ab}$	8.0 ± 2.1$_{a}$	22.3 ± 2.9$_{ab}$	41.7 ± 4.9$_{b}$	14.3 ± 0.7$_{ab}$
	2011	1.7 ± 1.7	1.7 ± 0.7	1.7 ± 0.7	1.0 ± 1.0	3.3 ± 2.4	1.0 ± 0.6
Rhopalidae	2010	1.7 ± 1.2	1.7 ± 0.7	1.0 ± 1.0	0.0 ± 0.0	68.7 ± 51.4	1.0 ± 0.6
	2011	13.0 ± 5.8	8.0 ± 1.2	1.3 ± 0.7	1.0 ± 1.0	7.7 ± 4.7	1.0 ± 0.6

Table 5 Continued

Aphididae	2010	294.0 ± 120.0	313.7 ± 28.9	206.7 ± 29.6	262.7 ± 38.8	361.0 ± 58.4	377.0 ± 76.2
	2011	353.3 ± 2.7^{a}	298.0 ± 52.4^{a}	511.0 ± 187.0^{a}	492.0 ± 3.6^{a}	867.0 ± 159.0^{b}	480.0 ± 58.6^{a}
Cercopidae	2010	1.0 ± 0.6	1.3 ± 0.7	2.7 ± 0.3	1.3 ± 0.9	1.3 ± 0.7	0.3 ± 0.3
	2011	5.3 ± 1.9	8.7 ± 2.2	9.0 ± 3.5	2.3 ± 0.9	4.7 ± 2.3	3.3 ± 1.5
Cicadellidae	2010	763.7 ± 41.0^{a}	695.3 ± 47.0^{a}	671.0 ± 79.7^{a}	751.0 ± 82.2^{a}	893.0 ± 44.9^{b}	851.3 ± 72.9^{b}
	2011*	568.3 ± 32.1	560.3 ± 21.2	490.7 ± 46.9	658.7 ± 40.6	673.0 ± 21.1	820.0 ± 191.0
Hymenoptera	2010	130.0 ± 16.5	142.3 ± 28.0	114.7 ± 16.0	162.0 ± 32.0	177.3 ± 39.1	113.7 ± 7.4
	2011	113.7 ± 1.8	105.7 ± 5.0	97.7 ± 7.8	111.3 ± 6.7	131.3 ± 8.3	107.0 ± 8.4
Chalcidoidea	2010	79.0 ± 6.9	68.0 ± 8.5	70.7 ± 3.3	82.3 ± 5.2	101.0 ± 19.3	93.3 ± 1.2
	2011*	64.3 ± .37	50.0 ± 2.1	79.3 ± 3.2	82.7 ± 1.8	87.0 ± 3.8	95.3 ± 9.0
Braconidae	2010	4.3 ± 0.3	3.7 ± 0.3	3.7 ± 0.9	6.0 ± 2.5	7.3 ± 0.9	5.0 ± 2.0
	2011	1.7 ± 0.7	3.0 ± 0.6	0.7 ± 0.7	0.3 ± 0.3	8.3 ± 3.2	2.0 ± 0.6
Ichneumonidae	2010*	3.7 ± 0.3	2.7 ± 0.9	8.7 ± 2.4	13.3 ± 3.4	14.7 ± 6.2	5.0 ± 1.5
	2011	3.3 ± 1.3	5.0 ± 1.0	3.3 ± 1.8	4.7 ± 2.3	3.3 ± 0.9	5.7 ± 1.5
Formicidae	2010	41.0 ± 10.3	64.7 ± 22.8	31.0 ± 14.4	58.7 ± 21.6	49.3 ± 14.2	9.0 ± 5.5
	2011*	35.0 ± 2.0$_{ab}$	37.0 ± 7.8 $_{b}$	13.3 ± 3.0$_{ab}$	17.3 ± 2.9$_{ab}$	26.0 ± 5.0$_{ab}$	2.3 ± 0.9$_{a}$
Diptera	2010	627.3 ± 28.9^{a}	566.3 ± 61.9^{a}	601.3 ± 89.5^{a}	706.3 ± 81.6^{a}	864.3 ± 34.1^{b}	862.0 ± 83.1^{b}
	2011	654.0 ± 122.0^{a}	472. 7 ± 29.5^{a}	558.0 ± 113.0^{a}	516.7 ± 60.1^{a}	756.0 ± 48.8^{b}	528.7 ± 43.9^{a}
Lepidoptera	2010	6.7 ± 0.9	5.7 ± 1.7	9.3 ± 2.4	23.7 ± 17.8	6.7 ± 1.2	3.3 ± 0.9
	2011	5.3 ± 1.9	7.7 ± 2.0	6.7 ± 0.3	4.7 ± 1.8	5.3 ± 1.7	6.7 ± 2.9

Table 5 Continued

Coleoptera	2010*	82.7 ± 23.5	84.0 ± 8.9	100.3 ± 27.0	184.3 ± 31.9	187.0 ± 6.4	176.0 ± 13.4
	2011*	153.3 ± 17.0	132.0 ± 37.8	98.3 ± 11.1	147.0 ± 20.7	219.0 ± 6.2	150.3 ± 33.0
Chrysomelidae	2010	11.3 ± 1.2	7.7 ± 2.7	20.3 ± 6.9	20.3 ± 9.4	19.0 ± 4.5	11.3 ± 1.9
	2011	23.0 ± 6.2	17.0 ± 7.0	7.7 ± 2.4	6.7 ± 1.8	23.3 ± 19.9	5.3 ± 1.2
Coccinellidae	2010*	61.7 ± 24.1	65.0 ± 12.3	63.7 ± 29.4	145.3 ± 31.8	144.7 ± 13.4	143.0 ± 19.3
	2011*	113.0 ± 16.5	104.0 ± 32.7	87.7 ± 13.2	132.7 ± 21.7	170.3 ± 9.8	139.3 ± 33.3
Curculionidae	2010	8.7 ± 1.5	10.7 ± 0.7	14.3 ± 8.4	14.7 ± 3.7	16.0 ± 4.4	15.7 ± 4.3
	2011	15.7 ± 6.0	9.3 ± 1.5	2.7 ± 0.3	6.3 ± 3.8	8.0 ± 2.5	5.0 ± 1.5
Hypera postica	2010	2.0 ± 1.0	2.7 ± 1.2	3.3 ± 1.5	3.0 ± 1.2	4.7 ± 2.7	5.7 ± 3.3
	2011	1.3 ± 0.3	0.3 ± 0.3	1.0 ± 0.6	0.3 ± 0.3	0.0 ± 0.0	2.0 ± 1.2
Sitona discoideus	2010	5.3 ± 1.5	4.3 ± 2.3	9.7 ± 6.8	6.3 ± 4.4	6.7 ± 3.7	5.0 ± 1.7
	2011	0.3 ± 0.3	0.7 ± 0.7	1.7 ± 0.7	2.7 ± 1.2	1.0 ± 0.6	2.3 ± 0.9
Arachnida	2010	10.3 ± 3.3	14.0 ± 5.8	8.3 ± 0.9	13.0 ± 1.2	11.3 ± 3.4	12.7 ± 0.9
	2011	12.3 ± 0.9	16.3 ± 3.2	11.3 ± 3.0	13.0 ± 2.9	31.0 ± 8.7	9.7 ± 2.2
Other Insects	2010	9.3 ± 2.9	4.3 ± 0.7	3.3 ± 0.7	8.3 ± 3.0	6.7 ± 0.9	10.3 ± 4.4
	2011	5.7 ± 1.2	7.3 ± 1.5	6.3 ± 2.0	4.7 ± 0.9	11.3 ± 2.3	6.0 ± 0.6

Table 6: Results of repeated-measures analysis of variance on arthropod abundance in pea/hay barley plots (2010-2011). In 2010, d.f. = 2, 4 (treatment effects) and d.f. = 16, 48 (interaction); in 2011, d.f. = 2, 4 (treatment effects) and d.f. = 12, 36 (interaction).

		Treatment effects		Treatment x date interactions	
Year	Taxon	F	P	F	P
2010	All Arthropods	15.58	0.013	1.44	0.166
	Orthoptera	2.72	0.180	1.04	0.469
	Acrididae	2.72	0.180	1.04	0.469
	Hemiptera	13.25	0.017	1.10	0.380
	Anthocoridae	3.42	0.136	2.00	0.033
	Lygaeidae	0.93	0.466	0.89	0.568
	Miridae	7.77	0.042	1.00	0.471
	Adelphocoris spp.	1.47	0.333	0.55	0.904
	Lygus spp.	2.59	0.190	0.35	0.988
	Trigonotylus spp.	11.71	0.021	0.97	0.505
	Nabidae	1.53	0.321	0.52	0.922
	Piesmatidae	2.58	0.190	0.99	0.478
	Rhopalidae	0.91	0.473	1.08	0.395
	Aphididae	9.36	0.031	2.11	0.024
	Cercopidae	0.43	0.677	0.88	0.593
	Cicadellidae	5.80	0.066	0.78	0.699
	Hymenoptera	7.46	0.045	0.99	0.487
	Chalcidoidea	12.59	0.019	1.11	0.376
	Braconidae	1.62	0.305	1.06	0.419
	Ichneumonidae	0.02	0.984	1.21	0.299
	Formicidae	14.25	0.015	3.40	0.000
	Diptera	49.83	0.001	0.68	0.803
	Lepidoptera	1.82	0.275	2.22	0.017
	Coleoptera	5.73	0.067	2.35	0.012
	Chrysomelidae	3.23	0.146	1.31	0.231
	Coccinellidae	0.61	0.589	2.04	0.029
	Curculionidae	11.28	0.023	1.53	0.128

Table 6 Continued

	Hypera postica	1.00	0.444	1.00	0.473
	Sitona discoideus	14.55	0.015	1.50	0.139
	Arachnida	17.51	0.011	1.12	0.369
	Other Insects	5.70	0.068	1.03	0.440
2011	All Arthropods	1.07	0.426	1.19	0.325
	Orthoptera	3.21	0.147	1.50	0.169
	Acrididae	2.82	0.172	1.55	0.151
	Hemiptera	2.164	0.231	1.38	0.220
	Anthocoridae	1.09	0.418	1.90	0.068
	Lygaeidae	9.15	0.032	3.32	0.003
	Miridae	5.75	0.067	1.92	0.065
	Adelphocoris spp.	0.76	0.526	0.29	0.987
	Lygus spp.	12.48	0.019	2.91	0.007
	Trigonotylus spp.	2.31	0.216	2.23	0.031
	Nabidae	17.13	0.011	2.32	0.026
	Piesmatidae	3.68	0.124	0.26	0.992
	Rhopalidae	4.37	0.099	0.96	0.506
	Aphididae	0.25	0.794	0.77	0.679
	Cercopidae	0.03	0.969	0.79	0.658
	Cicadellidae	1.88	0.265	1.15	0.351
	Hymenoptera	2.40	0.207	0.92	0.542
	Chalcidoidea	1.07	0.425	0.68	0.758
	Braconidae	0.75	0.530	0.75	0.694
	Ichneumonidae	2.20	0.227	1.26	0.283
	Formicidae	10.03	0.028	2.13	0.040
	Diptera	1.95	0.257	1.23	0.304
	Lepidoptera	9.66	0.029	1.23	0.301
	Coleoptera	10.94	0.024	2.81	0.008
	Chrysomelidae	0.49	0.647	0.66	0.774
	Coccinellidae	1.84	0.271	1.70	0.107
	Curculionidae	52.88	0.001	3.37	0.002

Table 6 Continued

Hypera postica	13.74	0.016	0.99	0.471
Sitona discoideus	42.24	0.002	3.41	0.002
Arachnida	30.22	0.004	0.51	0.896
Other Insects	0.51	0.637	0.51	0.894

Table 7: Mean with standard error of arthropods collected from pea/hay barley plots of the three treatments. Mean followed by different letter differ significantly from those of other treatments for the same year. (LSD test; α = 0.05). ^{a} represents treatment x date effects ($p<0.05$), $_{a}$ represents management effect ($p<0.05$).

		Mean ± SE number collected (PHB)		
Taxon	Year	Chemical	Graze	Mechanical
All Arthropods	2010	$3900 \pm 133_{a}$	$5088 \pm 280_{b}$	$3871 \pm 128_{a}$
	2011	2277 ± 93	2419 ± 138	2731 ± 276
Orthoptera	2010	34.7 ± 8.5	19.3 ± 0.3	15.7 ± 7.7
	2011	20.0 ± 5.7	29.0 ± 4.9	13.7 ± 2.7
Acrididae	2010	34.7 ± 8.5	19.3 ± 0.3	15.7 ± 7.7
	2011	19.7 ± 5.6	27.3 ± 4.4	13.7 ± 2.7
Hemiptera	2010	$2433 \pm 95_{a}$	$3430 \pm 252_{b}$	$2476 \pm 89_{a}$
	2011	1587 ± 17	1735 ± 162	2101 ± 285
Anthocoridae	2010	1.7 ± 0.9	1.3 ± 0.3	0.0 ± 0.0
	2011	0.3 ± 0.3	4.0 ± 2.7	0.7 ± 0.7
Lygaeidae	2010	15.7 ± 0.9	17.7 ± 8.7	6.3 ± 1.5
	2011	18.3 ± 6.5^{a}	76.0 ± 26.2^{b}	7.3 ± 1.9^{a}
Miridae	2010	$605.3 \pm 50.6_{a}$	$771.7 \pm 68.2_{b}$	$600.7 \pm 42.1_{a}$
	2011	336.3 ± 33.2	466.3 ± 24.7	459.7 ± 96.2
Adelphocoris spp.	2010	0.3 ± 0.3	1.3 ± 0.7	0.7 ± 0.7
	2011	8.3 ± 1.2	10.7 ± 4.8	7.0 ± 2.9
Lygus spp.	2010	16.7 ± 5.9	24.3 ± 11.4	32.3 ± 15.4
	2011	67.3 ± 17.4^{a}	208.3 ± 33.4^{b}	36.0 ± 3.8^{a}
Trigonotylus spp.	2010	$581.7 \pm 52.5_{a}$	$737.3 \pm 60.1_{b}$	$561.0 \pm 42.5_{a}$
	2011	239.0 ± 37.0^{a}	229.7 ± 8.8^{a}	403.0 ± 105.0^{b}

Table 7 Continued

Nabidae	2010	83.7 ± 13.9	84.7 ± 7.0	110.3 ± 13.2
	2011	50.7 ± 5.7^{a}	64.3 ± 6.4^{b}	39.7 ± 6.1^{a}
Piesmatidae	2010	10.7 ± 3.2	11.3 ± 4.7	4.3 ± 1.5
	2011	1.3 ± 0.9	0.3 ± 0.3	0.3 ± 0.3
Rhopalidae	2010	1.7 ± 0.3	5.7 ± 4.3	1.3 ± 0.3
	2011	1.0 ± 0.6	38.7 ± 26.9	1.3 ± 0.7
Aphididae	2010	365.3 ± 24.8^{a}	756.0 ± 157.0^{b}	430.0 ± 74.5^{a}
	2011	783.0 ± 102.0	719.7 ± 56.3	794.0 ± 213.0
Cercopidae	2010	1.3 ± 0.9	0.3 ± 0.3	0.7 ± 0.3
	2011	1.3 ± 1.3	1.0 ± 0.6	1.0 ± 0.6
Cicadellidae	2010	1338 ± 66	1773 ± 93	1308 ± 172
	2011	381 ± 54	355 ± 41	792 ± 318
Hymenoptera	2010	94.3 ± 22.0$_{a}$	120.0 ± 23.6$_{b}$	85.3 ± 10.5$_{a}$
	2011	78.7 ± 8.1	84.3 ± 11.7	57.0 ± 9.6
Chalcidoidea	2010	54.0 ± 15.6$_{a}$	88.0 ± 17.6$_{b}$	68.0 ± 9.3$_{a}$
	2011	58.7 ± 5.8	49.7 ± 9.0	51.3 ± 8.4
Braconidae	2010	6.0 ± 1.5	5.0 ± 0.6	4.3 ± 0.7
	2011	1.7 ± 0.7	3.3 ± 1.5	2.3 ± 0.7
Ichneumonidae	2010	7.7 ± 1.5	8.7 ± 3.5	8.3 ± 0.9
	2011	3.7 ± 1.5	6.7 ± 2.0	2.0 ± 0.6
Formicidae	2010	21.7 ± 6.8^{a}	17.7 ± 3.5^{a}	3.0 ± 1.5^{b}
	2011	7.0 ± 3.5	9.7 ± 2.9	0.7 ± 0.7
Diptera	2010	905 ± 36$_{ab}$	1200 ± 15$_{b}$	810 ± 39$_{a}$
	2011	412 ± 55	451 ± 69	317 ± 49
Lepidoptera	2010	10.3 ± 5.3	6.7 ± 0.9	21.0 ± 7.8
	2011	6.0 ± 1.2$_{a}$	21.3 ± 9.2$_{b}$	2.3 ± 0.3$_{a}$
Coleoptera	2010	405.3 ± 11.0^{a}	280.7 ± 24.1^{b}	444.0 ± 14.2^{a}
	2011	164.3 ± 45.2^{a}	77.3 ± 7.9^{b}	230.7 ± 24.9^{a}
Chrysomelidae	2010	5.0 ± 1.5	13.3 ± 2.9	10.7 ± 5.2
	2011	4.3 ± 2.4	1.7 ± 0.3	3.7 ± 1.7
Coccinellidae	2010	33.0 ± 5.3	57.3 ± 20.6	46.0 ± 9.3
	2011	48.0 ± 16.1	40.7 ± 6.1	79.3 ± 16.8

Table 7 Continued

Curculionidae	2010	$363.0 \pm 14.4_a$	$205.7 \pm 17.0_b$	$383.3 \pm 24.3_a$
	2011	111.3 ± 33.2^a	34.0 ± 13.3^b	145.7 ± 11.1^a
Hypera postica	2010	0.0 ± 0.0	0.3 ± 0.3	0.0 ± 0.0
	2011	0.7 ± 0.3	2.7 ± 0.7	0.0 ± 0.0
Sitona discoideus	2010	$358.0 \pm 14.8_a$	$197.3 \pm 20.1_b$	$379.3 \pm 24.2_a$
	2011	107.7 ± 32.2^a	26.0 ± 13.1^b	144.7 ± 11.3^a
Arachnida	2010	$14.3 \pm 3.2_a$	$25.3 \pm 3.3_b$	$15.3 \pm 1.9_a$
	2011	$7.0 \pm 2.1_a$	$17.0 \pm 2.5_b$	$8.0 \pm 1.5_a$
Other Insects	2010	2.3 ± 0.9	6.0 ± 1.2	3.3 ± 0.3
	2011	2.7 ± 1.5	4.3 ± 1.2	1.7 ± 0.3

Table 8: Results of repeated-measures analysis of variance on arthropod abundance in summer fallow plots (2010-2011). In 2010, d.f. = 2, 4 (treatment effects) and d.f. = 16, 48 (interaction); in 2011, d.f. = 2, 4 (treatment effects) and d.f. = 12, 36 (interaction).

		Treatment effects		Treatment x date interactions	
Year	Taxon	F	P	F	P
2010	All Arthropods	143.20	0.000	3.14	0.001
	Orthoptera	19.67	0.009	5.28	0.000
	Acrididae	19.67	0.009	5.28	0.000
	Hemiptera	34.96	0.003	2.60	0.006
	Anthocoridae	1.00	0.444	1.00	0.473
	Lygaeidae	7.38	0.046	4.06	0.000
	Miridae	55.74	0.001	2.26	0.015
	Adelphocoris spp.	1.00	0.444	1.00	0.473
	Lygus spp.	22.53	0.007	5.61	0.000
	Trigonotylus spp.	2.48	0.199	1.72	0.076
	Nabidae	4.64	0.091	1.13	0.358
	Piesmatidae	3.36	0.139	0.725	0.755
	Rhopalidae	2.90	0.166	1.66	0.089

Table 8 Continued

	Aphididae	75.36	0.001	4.18	0.000
	Cercopidae	1.00	0.444	1.00	0.473
	Cicadellidae	13.27	0.017	1.96	0.037
	Hymenoptera	44.31	0.002	1.75	0.069
	Chalcidoidea	38.71	0.002	1.45	0.160
	Braconidae	2.30	0.216	0.79	0.692
	Ichneumonidae	6.33	0.058	3.38	0.001
	Formicidae	31.96	0.003	2.48	0.008
	Diptera	8.50	0.036	4.80	0.000
	Lepidoptera	36.77	0.003	7.52	0.000
	Coleoptera	9.66	0.029	1.54	0.126
	Chrysomelidae	4.49	0.095	1.76	0.067
	Coccinellidae	36.91	0.003	1.69	0.081
	Curculionidae	4.73	0.088	0.27	0.997
	Hypera postica	-	-	-	-
	Sitona discoideus	0.05	0.950	0.33	0.992
	Arachnida	4.27	0.102	0.77	0.174
	Other Insects	0.40	0.694	1.06	0.414
2011	All Arthropods	15.88	0.013	3.42	0.002
	Orthoptera	5.76	0.067	1.66	0.119
	Acrididae	5.76	0.067	1.66	0.119
	Hemiptera	12.90	0.018	6.56	0.000
	Anthocoridae	1.00	0.444	1.00	0.468
	Lygaeidae	6.65	0.054	2.31	0.026
	Miridae	7.89	0.041	7.83	0.000
	Adelphocoris spp.	1.00	0.444	1.00	0.468
	Lygus spp.	4.07	0.109	2.13	0.040
	Trigonotylus spp.	1.89	0.264	1.03	0.446
	Nabidae	70.95	0.001	3.88	0.001
	Piesmatidae	1.43	0.340	0.93	0.533
	Rhopalidae	2.70	0.181	2.31	0.026

Table 8 Continued

Aphididae	16.39	0.012	1.41	0.208
Cercopidae	1.00	0.444	1.00	0.468
Cicadellidae	13.97	0.016	4.39	0.000
Hymenoptera	54.01	0.001	2.53	0.016
Chalcidoidea	9.53	0.030	2.51	0.016
Braconidae	1.51	0.325	1.43	0.200
Ichneumonidae	9.16	0.032	0.93	0.531
Formicidae	7.62	0.043	3.01	0.005
Diptera	18.69	0.009	3.41	0.002
Lepidoptera	9.24	0.032	4.32	0.000
Coleoptera	9.34	0.031	3.14	0.004
Chrysomelidae	1.41	0.343	0.91	0.545
Coccinellidae	3.40	0.137	0.98	0.486
Curculionidae	7.06	0.049	2.21	0.033
Hypera postica	-	-	-	-
Sitona discoideus	-	-	-	-
Arachnida	61.03	0.001	1.57	0.144
Other Insects	1.00	0.444	1.00	0.468

Table 9: Mean with standard error of arthropods collected from summer fallow plots of the three treatments. Mean followed by different letter differ significantly from those of other treatments for the same year. (LSD test; α = 0.05). ^{a} represents treatment x date effects ($p<0.05$), $_{a}$ represents management effect ($p<0.05$).

		Mean ± SE number collected (Fallow)		
Taxon	Year	Chemical	Graze	Mechanical
All Arthropods	2010	592.3 ± 39.2^{a}	384.0 ± 82.1^{a}	89.7 ± 18.5^{b}
	2011	668.0 ± 251^{a}	305.7 ± 63.2^{ab}	13.7 ± 3.4^{b}
Orthoptera	2010	10.0 ± 1.5^{a}	12.0 ± 3.6^{a}	0.7 ± 0.3^{b}
	2011	9.7 ± 2.6	4.0 ± 2.1	0.7 ± 0.3
Acrididae	2010	10.0 ± 1.5^{a}	12.0 ± 3.6^{a}	0.7 ± 0.3^{b}
	2011	9.7 ± 2.6	4.0 ± 2.1	0.7 ± 0.3

Table 9 Continued

Hemiptera	2010	277.3 ± 49.4^{a}	226.0 ± 85.0^{a}	33.0 ± 6.8^{b}
	2011	364.0 ± 167.0^{a}	74.3 ± 19.2^{b}	1.0 ± 0.6^{c}
Anthocoridae	2010	0.3 ± 0.3	0.0 ± 0.0	0.0 ± 0.0
	2011	0.0 ± 0.0	0.7 ± 0.7	0.0 ± 0.0
Lygaeidae	2010	60.3 ± 25.9^{a}	30.7 ± 1.9^{a}	0.0 ± 0.0^{b}
	2011	80.3 ± 54.3	20.3 ± 15.6	0.0 ± 0.0
Miridae	2010	69.7 ± 10.5^{a}	34.7 ± 6.1^{ab}	4.7 ± 1.2^{b}
	2011	106.7 ± 43.8^{a}	15.3 ± 4.3^{ab}	0.7 ± 0.3^{b}
Adelphocoris	2010	0.3 ± 0.3	0.0 ± 0.0	0.0 ± 0.0
	2011	1.3 ± 1.3	0.0 ± 0.0	0.0 ± 0.0
Lygus spp.	2010	45.3 ± 5.2^{a}	13.0 ± 4.7^{ab}	3.7 ± 1.2^{b}
	2011	44.0 ± 34.6	7.7 ± 3.2	0.3 ± 0.3
Trigonotylus spp.	2010	3.7 ± 1.9	0.7 ± 0.7	0.3 ± 0.3
	2011	32.0 ± 29.0	1.7 ± 1.2	0.0 ± 0.0
Nabidae	2010	7.0 ± 3.8	0.7 ± 0.7	0.0 ± 0.0
	2011	8.7 ± 1.2^{a}	0.3 ± 0.3^{b}	0.3 ± 0.3^{b}
Piesmatidae	2010	3.0 ± 1.5	34.3 ± 27.4	3.7 ± 2.2
	2011	0.7 ± 0.3	1.0 ± 0.6	0.0 ± 0.0
Rhopalidae	2010	4.0 ± 2.5	8.7 ± 5.2	1.0 ± 1.0
	2011	2.7 ± 1.7	0.3 ± 0.3	0.0 ± 0.0
Aphididae	2010	52.7 ± 10.4^{a}	5.7 ± 1.2^{b}	10.3 ± 5.0^{a}
	2011	18.3 ± 6.2$_{a}$	3.0 ± 1.5$_{b}$	0.0 ± 0.0$_{b}$
Cercopidae	2010	0.0 ± 0.0	0.3 ± 0.3	0.0 ± 0.0
	2011	0.3 ± 0.3	0.0 ± 0.0	0.0 ± 0.0
Cicadellidae	2010	75.0 ± 14.4^{a}	105.3 ± 49.4^{a}	11.3 ± 3.2^{b}
	2011	139.3 ± 76.8^{a}	31.3 ± 5.0^{ab}	0.0 ± 0.0^{b}
Hymenoptera	2010	69.3 ± 7.7$_{a}$	18.0 ± 4.6$_{ab}$	7.0 ± 3.6$_{b}$
	2011	28.7 ± 6.6^{a}	17.3 ± 2.2^{ab}	1.0 ± 1.0^{b}
Chalcidoidea	2010	17.0 ± 0.6$_{a}$	7.0 ± 2.0$_{ab}$	3.3 ± 2.0$_{b}$
	2011	10.0 ± 2.1^{a}	4.3 ± 2.0^{ab}	0.0 ± 0.0^{b}
Braconidae	2010	2.3 ± 1.2	2.0 ± 0.6	0.7 ± 0.7
	2011	2.0 ± 1.5	0.3 ± 0.3	0.0 ± 0.0

Table 9 Continued

Ichneumonidae	2010	4.7 ± 1.2	1.0 ± 1.0	0.0 ± 0.0
	2011	3.0 ± 1.2$_{a}$	3.0 ± 1.2$_{a}$	0.0 ± 0.0$_{b}$
Formicidae	2010	42.0 ± 8.0^{a}	5.0 ± 0.6^{b}	1.7 ± 0.9^{b}
	2011	9.0 ± 3.8^{a}	7.0 ± 1.5^{a}	0.7 ± 0.7^{b}
Diptera	2010	131.3 ± 9.9^{a}	104.3 ± 27.7^{a}	42.0 ± 7.2^{b}
	2011	219.3 ± 74.3^{a}	204.0 ± 81.6^{a}	9.3 ± 2.3^{b}
Lepidoptera	2010	42.3 ± 6.5^{a}	1.3 ± 0.3^{b}	2.0 ± 1.0^{b}
	2011	26.3 ± 15.1^{a}	2.3 ± 1.9^{b}	0.0 ± 0.0^{b}
Coleoptera	2010	58.7 ± 21.2$_{a}$	20.3 ± 4.4$_{a}$	4.3 ± 2.0$_{b}$
	2011	13.3 ± 5.8^{a}	2.3 ± 0.9^{a}	1.0 ± 1.0^{b}
Chrysomelidae	2010	43.3 ± 23.2	16.7 ± 5.9	1.3 ± 1.3
	2011	2.0 ± 0.6	0.7 ± 0.7	1.0 ± 1.0
Coccinellidae	2010	9.7 ± 3.5$_{a}$	0.7 ± 0.3$_{b}$	1.3 ± 0.3$_{b}$
	2011	2.7 ± 1.5	0.7 ± 0.3	0.0 ± 0.0
Curculionidae	2010	5.0 ± 1.0	1.7 ± 1.2	1.7 ± 1.2
	2011	7.7 ± 4.1^{a}	0.7 ± 0.3^{b}	0.0 ± 0.0^{b}
Hypera postica	2010	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
	2011	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Sitona discoideus	2010	2.0 ± 1.5	1.3 ± 1.3	1.7 ± 1.2
	2011	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Arachnida	2010	3.0 ± 0.6	2.0 ± 1.0	0.3 ± 0.3
	2011	6.7 ± 0.9$_{a}$	1.3 ± 0.3$_{b}$	0.7 ± 0.3$_{b}$
Other Insects	2010	0.3 ± 0.3	0.0 ± 0.0	0.3 ± 0.3
	2011	0.3 ± 0.3	0.0 ± 0.0	0.0 ± 0.0

Table 10: Results of repeated-measures analysis of variance on arthropod abundance in alfalfa plots (2010-2011). In 2010, d.f. = 2, 4 (cultivar effects) and d.f. = 16, 48 (interaction); in 2011, d.f. = 2, 4 (cultivar effects) and d.f. = 12, 36 (interaction).

		Cultivar effects		Cultivar x date interactions	
Year	Taxon	F	P	F	P
2010	All Arthropods	5.50	0.072	0.95	0.520
	Orthoptera	0.33	0.739	0.91	0.559
	Acrididae	0.26	0.782	0.81	0.670
	Hemiptera	4.18	0.105	0.81	0.672
	Anthocoridae	0.17	0.851	1.45	0.159
	Lygaeidae	0.18	0.846	0.76	0.719
	Miridae	2.03	0.246	0.74	0.743
	Adelphocoris spp.	0.08	0.923	0.31	0.994
	Lygus spp.	1.59	0.310	1.07	0.406
	Trigonotylus spp.	0.34	0.728	0.73	0.750
	Nabidae	0.08	0.922	0.29	0.995
	Piesmatidae	0.52	0.629	0.97	0.501
	Rhopalidae	3.05	0.157	0.45	0.960
	Aphididae	20.32	0.008	0.68	0.795
	Cercopidae	1.69	0.299	1.15	0.338
	Cicadellidae	2.31	0.215	0.87	0.601
	Hymenoptera	4.45	0.096	0.64	0.838
	Chalcidoidea	0.39	0.700	0.66	0.819
	Braconidae	2.55	0.193	0.811	0.667
	Ichneumonidae	8.83	0.034	0.667	0.810
	Formicidae	13.31	0.017	1.27	0.255
	Diptera	1.06	0.428	0.57	0.892
	Lepidoptera	2.12	0.236	0.67	0.806
	Coleoptera	3.48	0.133	1.84	0.054
	Chrysomelidae	0.54	0.618	0.49	0.939
	Coccinellidae	0.90	0.475	1.55	0.121
	Curculionidae	3.36	0.139	2.12	0.023
	Hypera postica	3.77	0.120	2.20	0.018

Table 10 Continued

	Sitona discoideus	1.73	0.287	0.74	0.736
	Arachnida	0.01	0.991	0.67	0.807
	Other Insects	3.18	0.149	1.38	0.194
2011	All Arthropods	1.51	0.325	0.53	0.880
	Orthoptera	0.68	0.558	0.70	0.742
	Acrididae	0.35	0.727	0.80	0.650
	Hemiptera	0.33	0.734	0.61	0.823
	Anthocoridae	0.32	0.741	0.65	0.788
	Lygaeidae	3.98	0.112	1.43	0.199
	Miridae	2.36	0.210	0.96	0.502
	Adelphocoris spp.	2.83	0.171	1.60	0.136
	Lygus spp.	2.07	0.242	0.85	0.600
	Trigonotylus spp.	0.11	0.900	1.18	0.330
	Nabidae	0.63	0.580	0.70	0.739
	Piesmatidae	0.72	0.540	0.62	0.808
	Rhopalidae	1.25	0.380	0.64	0.794
	Aphididae	1.56	0.315	0.35	0.972
	Cercopidae	2.01	0.249	0.77	0.673
	Cicadellidae	0.93	0.465	0.82	0.631
	Hymenoptera	3.69	0.124	0.71	0.736
	Chalcidoidea	2.96	0.163	0.97	0.500
	Braconidae	0.21	0.816	0.30	0.986
	Ichneumonidae	1.12	0.412	0.45	0.931
	Formicidae	3.97	0.112	1.60	0.136
	Diptera	0.22	0.814	0.57	0.851
	Lepidoptera	0.18	0.839	0.92	0.536
	Coleoptera	2.17	0.231	0.50	0.902
	Chrysomelidae	0.43	0.676	1.55	0.151
	Coccinellidae	0.00	0.998	1.04	0.435
	Curculionidae	2.22	0.225	0.49	0.905
	Hypera postica	2.17	0.230	0.50	0.900

Table 10 Continued

Sitona discoideus	0.06	0.942	0.07	1.000
Arachnida	0.16	0.878	1.03	0.445
Other Insects	0.41	0.689	1.76	0.094

Table 11: Mean with standard error of arthropods collected from the three alfalfa cultivars. Mean followed by different letter differ significantly from those of other cultivars for the same year. (LSD test; $\alpha = 0.05$).

		Mean ± SE number collected (Alfalfa)		
Taxon	Year	Cimarron SR	HayGrazer	Shaw
All Arthropods	2010	9097 ± 772	10701 ± 85	7845 ± 749
	2011	6461 ± 835	4975 ± 735	4799 ± 756
Orthoptera	2010	43.67 ± 6.06	63.7 ± 12.0	53.3 ± 21.7
	2011	15.0 ± 4.0	18.7 ± 6.8	21.7 ± 4.4
Acrididae	2010	43.67 ± 6.06	61.3 ± 11.8	52.3 ± 21.9
	2011	15.0 ± 4.0	18.7 ± 6.8	20.7 ± 4.8
Hemiptera	2010	4780 ± 429	5678 ± 258	4193 ± 520
	2011	1254 ± 320	1051 ± 104	1040 ± 105
Anthocoridae	2010	44.67 ± 6.96	46.0 ± 7.77	43.33 ± 8.97
	2011	5.7 ± 1.3	4.7 ± 2.2	3.0 ± 1.5
Lygaeidae	2010	5.67 ± 0.88	6.33 ± 2.03	5.0 ± 0.58
	2011	7.3 ± 1.5	24.7 ± 3.9	7.3 ± 4.3
Miridae	2010	1846 ± 508	1381.3 ± 94.4	1359 ± 296
	2011	484 ± 148	275 ± 49	403 ± 79
Adelphocoris spp.	2010	238 ± 104	179.7 ± 44.1	239.3 ± 88.3
	2011	60.7 ± 10.7	41.3 ± 4.7	96.0 ± 20.7
Lygus spp.	2010	1461 ± 446	1100 ± 58	1018 ± 217
	2011	404 ± 142	222 ± 49	293 ± 62
Trigonotylus spp.	2010	114.3 ± 56.6	80.0 ± 7.64	67.7 ± 11.1
	2011	1.3 ± 0.7	1.0 ± 1.0	1.3 ± 0.9
Nabidae	2010	277.3 ± 49.3	319.7 ± 68.8	317 ± 94
	2011	56.0 ± 12.2	54.3 ± 6.2	45.7 ± 8.4

Table 11 Continued

Piesmatidae	2010	34.67 ± 2.03	45.67 ± 9.84	35.33 ± 5.78
	2011	1.7 ± 0.3	2.3 ± 0.8	2.3 ± 0.7
Rhopalidae	2010	2.67 ± 1.20	3.67 ± 2.19	5.33 ± 1.86
	2011	0.7 ± 0.3	1.0 ± 0.6	1.7 ± 0.3
Aphididae	2010	1929.0 ± 89.5$_a$	3256 ± 349$_b$	1927.3 ± 90.2$_a$
	2011	476.0 ± 88.4	525.7 ± 81.0	416.7 ± 34.8
Cercopidae	2010	47.7 ± 18.0	15.0 ± 9.61	24.0 ± 12.9
	2011	87.0 ± 69.5	12.3 ± 5.8	22.0 ± 8.9
Cicadellidae	2010	561 ± 117	566.7 ± 64.3	432.3 ± 50.9
	2011	120.7 ± 17.7	133.0 ± 2.7	121.7 ± 12.7
Hymenoptera	2010	337.7 ± 2.0	477.3 ± 40.3	380.0 ± 51.7
	2011	208.7 ± 55.6	133.7 ± 22.3	146.7 ± 28.7
Chalcidoidea	2010	233.7 ± 9.9	276.7 ± 53.5	250.3 ± 55.4
	2011	126.3 ± 51.1	60.0 ± 8.7	58.7 ± 8.8
Braconidae	2010	23.0 ± 2.1	16.7 ± 2.9	18.7 ± 1.7
	2011	9.7 ± 3.7	7.7 ± 0.7	9.0 ± 3.5
Ichneumonidae	2010	45.3 ± 2.4$_a$	44.0 ± 3.2$_a$	35.3 ± 0.9$_b$
	2011	67.3 ± 2.9	54.3 ± 11.9	66.7 ± 18.8
Formicidae	2010	31.3 ± 9.0$_a$	137.7 ± 20.3$_b$	70.7 ± 18.4$_a$
	2011	4.0 ± 2.0	9.0 ± 3.8	9.7 ± 2.6
Diptera	2010	1316 ± 127	1373 ± 138	1178 ± 73
	2011	330.7 ± 41.5	287.0 ± 42.8	282.7 ± 24.9
Lepidoptera	2010	18.3 ± 4.8	17.3 ± 2.0	27.3 ± 1.5
	2011	6.0 ± 1.2	3.7 ± 0.9	5.7 ± 2.2
Coleoptera	2010	2521 ± 474	3009 ± 266	1925 ± 120
	2011	4603 ± 504	3449 ± 883	3266 ± 853
Chrysomelidae	2010	19.7 ± 6.2	24.3 ± 7.7	14.0 ± 4.0
	2011	2.7 ± 1.2	4.3 ± 1.5	2.3 ± 1.3
Coccinellidae	2010	109.0 ± 14.0	123.3 ± 11.9	84.7 ± 13.0
	2011	16.7 ± 1.5	14.7 ± 2.9	18.0 ± 5.1
Curculionidae	2010	2245 ± 458	2764 ± 282	1732 ± 146
	2011	4568 ± 498	3415 ± 886	3234 ± 855

Table 11 Continued

Hypera postica	2010	2105 ± 388	2701 ± 283	1680 ± 150
	2011	4554 ± 494	3402 ± 886	3217 ± 858
Sitona discoideus	2010	123.3 ± 73.5	44.7 ± 4.9	39.0 ± 14.4
	2011	9.0 ± 4.2	8.0 ± 1.5	10.0 ± 5.5
Arachnida	2010	65.0 ± 4.6	65.3 ± 8.6	62.7 ± 5.8
	2011	39.3 ± 19.4	29.3 ± 3.5	33.0 ± 4.0
Other Insects	2010	16.3 ± 2.2	17.0 ± 2.0	25.0 ± 4.0
	2011	4.0 ± 0.6	2.3 ± 0.9	3.3 ± 1.5

Table 12: Elaterids collected from Fort Ellis in 2010 and 2011.

Year	Total larvae	Total adults	Larvae species	Adult species
2010	97	15	*Aeolus mellillus*	*Aeolus mellillus*
			Dalopius sp.	*Agriotes criddlei*
			Hypnoidus leei	*Dalopius spretus*
			Limonius infuscatus	*Hadromorphus glaucus*
			Athous sierrae varius	*Pseudanostirus* sp.
			Hemicrepidius sp. nr. *carbonatus*	*Hemicrepidius* sp. nr. *carbonatus*
			Selatosomus aeripennis	
2011	291	10	*Aeolus mellillus*	*Agriotes criddlei*
			Dalopius sp.	*Dalopius spretus*
			Hypnoidus leei	*Hadromorphus glaucus*
			Limonius infuscatus	
			Athous sierrae varius	
			Hemicrepidius sp. nr. *carbonatus*	
			Selatosomus aeripennis	
			Agriotes sp.	
			Melanotus longulus oregonensis	

Table 13: Results of a Kruskal–Wallis one-way ANOVA on total wireworms in alfalfa, rotational, and continuous spring wheat plots for 2010 and 2011 with 2 d. f. Mean ± SE followed by different letters are significantly different (Dunn's Test; $\alpha = 0.05$).

	Mean ± SE number collected			One-way ANOVA	
Year	Alfalfa	Rotation	Continuous SW	H	P
2010	1.11 ± 0.42^{a}	1.00 ± 0.32^{a}	6.67 ± 1.41^{b}	31.55	<0.001
2011	4.33 ± 1.48^{a}	4.04 ± 1.16^{a}	12.56 ± 2.33^{b}	28.73	<0.001

Table 14: Results of a Kruskal–Wallis one-way ANOVA on total wireworms in alfalfa, summer fallow, pea/hay barley, rotational, and continuous spring wheat plots for 2010 and 2011 with 4 d. f. Mean ± SE followed by different letters are significantly different (Student-Newman-Keuls test; $\alpha = 0.05$).

	Mean ± SE number collected					One-way ANOVA	
Year	Fallow	PHB	Rotational SW	Alfalfa	Continuous SW	H	P
2010	0.78 ± 0.43^{ab}	0.22 ± 0.22^{b}	2.00 ± 0.75^{a}	1.11 ± 0.42^{ab}	6.67 ± 1.41^{c}	38.07	<0.001
2011	8.33 ± 2.71^{a}	2.33 ± 1.17^{b}	1.44 ± 0.97^{c}	4.33 ± 1.48^{d}	12.56 ± 2.33^{e}	49.92	<0.001

Table 15: Results of a Kruskal–Wallis one-way ANOVA on total wireworms in the three different alfalfa cultivar plots for 2010 and 2011 with 2 d. f. Mean ± SE followed by different letters are significantly different (Student-Newman-Keuls test; α = 0.05).

	Mean ± SE number collected			One-way ANOVA	
Year	Cimarron SR	Hay Grazer	Shaw	H	P
2010	2.67 ± 0.33^a	0.0 ± 0.0^a	0.67 ± 0.33^a	5.467	0.065
2011	8.33 ± 3.53^a	2.67 ± 1.20^a	2.00 ± 0.57^a	4.977	0.083

Table 16: Results of a Kruskal–Wallis one-way ANOVA on total wireworms in the three different treatment plots for 2010 and 2011 with 2 d. f. Mean ± SE followed by different letters are significantly different (Student-Newman-Keuls test; α = 0.05).

	Mean ± SE number collected			One-way ANOVA	
Year	Chemical	Graze	Mechanical	H	P
2010	1.22 ± 0.60^a	1.33 ± 0.69^a	0.44 ± 0.34^a	3.016	0.221
2011	5.89 ± 2.17^a	1.78 ± 0.57^a	4.44 ± 2.66^a	5.961	0.051

Table 17: Results of a Kruskal–Wallis one-way ANOVA on total *A. mellillus* in alfalfa, rotational, and continuous spring wheat plots for 2010 and 2011 with 2 d. f. Mean ± SE followed by different letters are significantly different (Dunn's Test; α = 0.05).

	Mean ± SE number collected			One-way ANOVA	
Year	Alfalfa	Rotation	Continuous SW	H	P
2010	0.44 ± 0.24^a	0.74 ± 0.28^a	6.33 ± 1.47^b	37.17	<0.001
2011	1.00 ± 0.53^a	1.41 ± 0.41^a	9.67 ± 2.29^b	30.81	<0.001

Table 18: Results of a Kruskal–Wallis one-way ANOVA on total *Dalopius* sp. in alfalfa, rotational, and continuous spring wheat plots for 2010 and 2011 with 2 d. f. Mean ± SE followed by different letters are significantly different (Dunn's Test; $\alpha = 0.05$).

	Mean ± SE number collected			One-way ANOVA	
Year	Alfalfa	Rotation	Continuous SW	H	P
2010	0.44 ± 0.29^{a}	0.04 ± 0.04^{a}	0.11 ± 0.11^{a}	2.830	0.243
2011	0.67 ± 0.44^{a}	1.00 ± 0.46^{a}	0.11 ± 0.11^{a}	3.189	0.203

Table 19: Results of a Kruskal–Wallis one-way ANOVA on total *H. leei* in alfalfa, rotational, and continuous spring wheat plots for 2010 and 2011 with 2 d. f. Mean ± SE followed by different letters are significantly different (Dunn's Test; $\alpha = 0.05$).

	Mean ± SE number collected			One-way ANOVA	
Year	Alfalfa	Rotation	Continuous SW	H	P
2010	0.0 ± 0.0^{a}	0.04 ± 0.04^{a}	0.11 ± 0.11^{a}	1.343	0.511
2011	2.11 ± 1.02^{a}	1.30 ± 0.62^{a}	1.67 ± 0.47^{a}	9.110	0.011

Table 20: Results of a Kruskal–Wallis one-way ANOVA on total other wireworm species in alfalfa, rotational, and continuous spring wheat plots for 2010 and 2011 with 2 d. f. Mean ± SE followed by different letters are significantly different (Dunn's Test; $\alpha = 0.05$).

	Mean ± SE number collected			One-way ANOVA	
Year	Alfalfa	Rotation	Continuous SW	H	P
2010	0.22 ± 0.15^{a}	0.19 ± 0.09^{a}	0.11 ± 0.11^{a}	0.352	0.839
2011	0.56 ± 0.24^{a}	0.33 ± 0.20^{a}	1.11 ± 0.54^{a}	3.998	0.135

Figure 3: Rank order of abundance of all major arthropod orders; all treatments, both years.

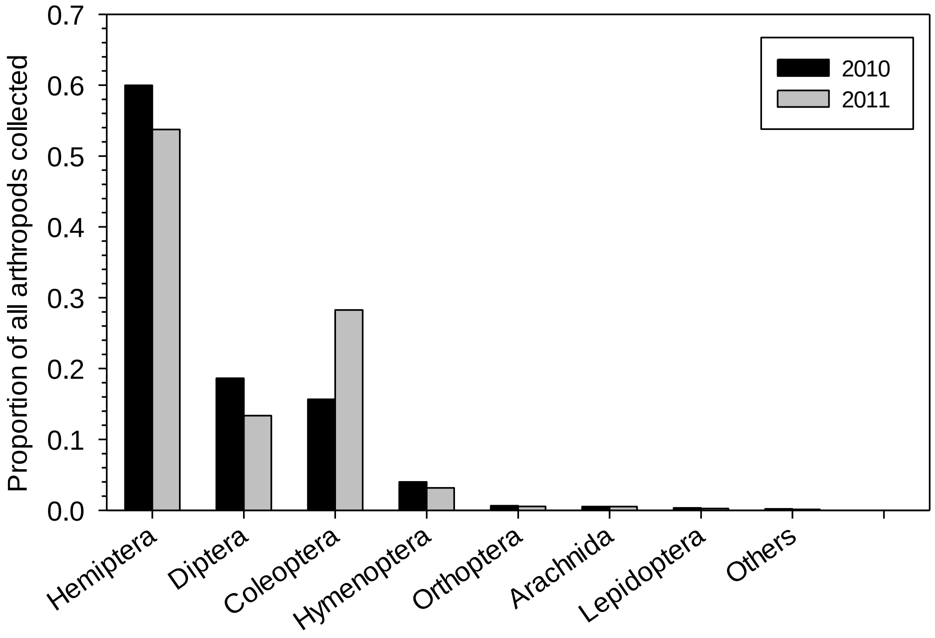


Figure 4: Rank order of abundance of all major arthropod families at Ft. Ellis (with Chalcidoidea included here though it is a superfamily); all treatments, both years.

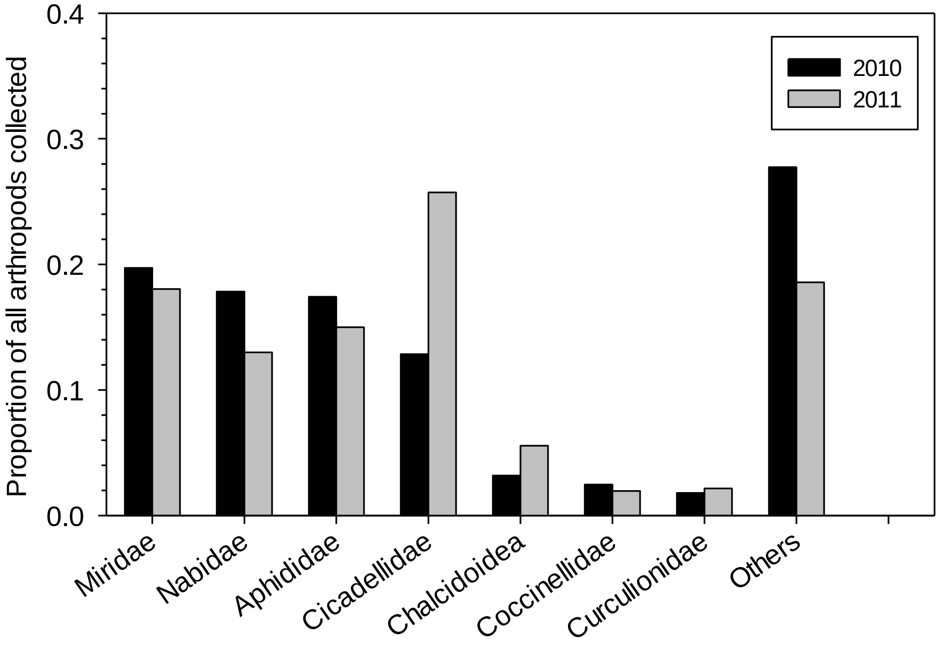


Figure 5: Average total counts (all samples) of arthropods by habitat plots in both years.

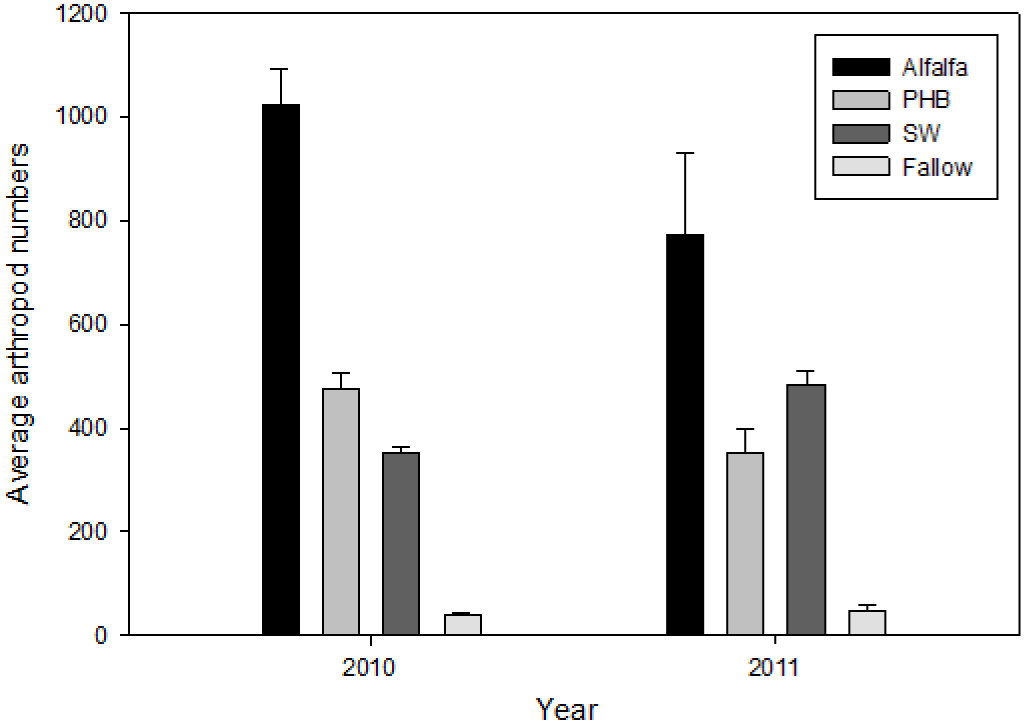


Figure 6: Abundance of major orders of insects and arachnids at Fort Ellis according to habitat in both years. Order of taxa in all habitats is based on their rank order of abundance in the spring wheat plots in 2010.

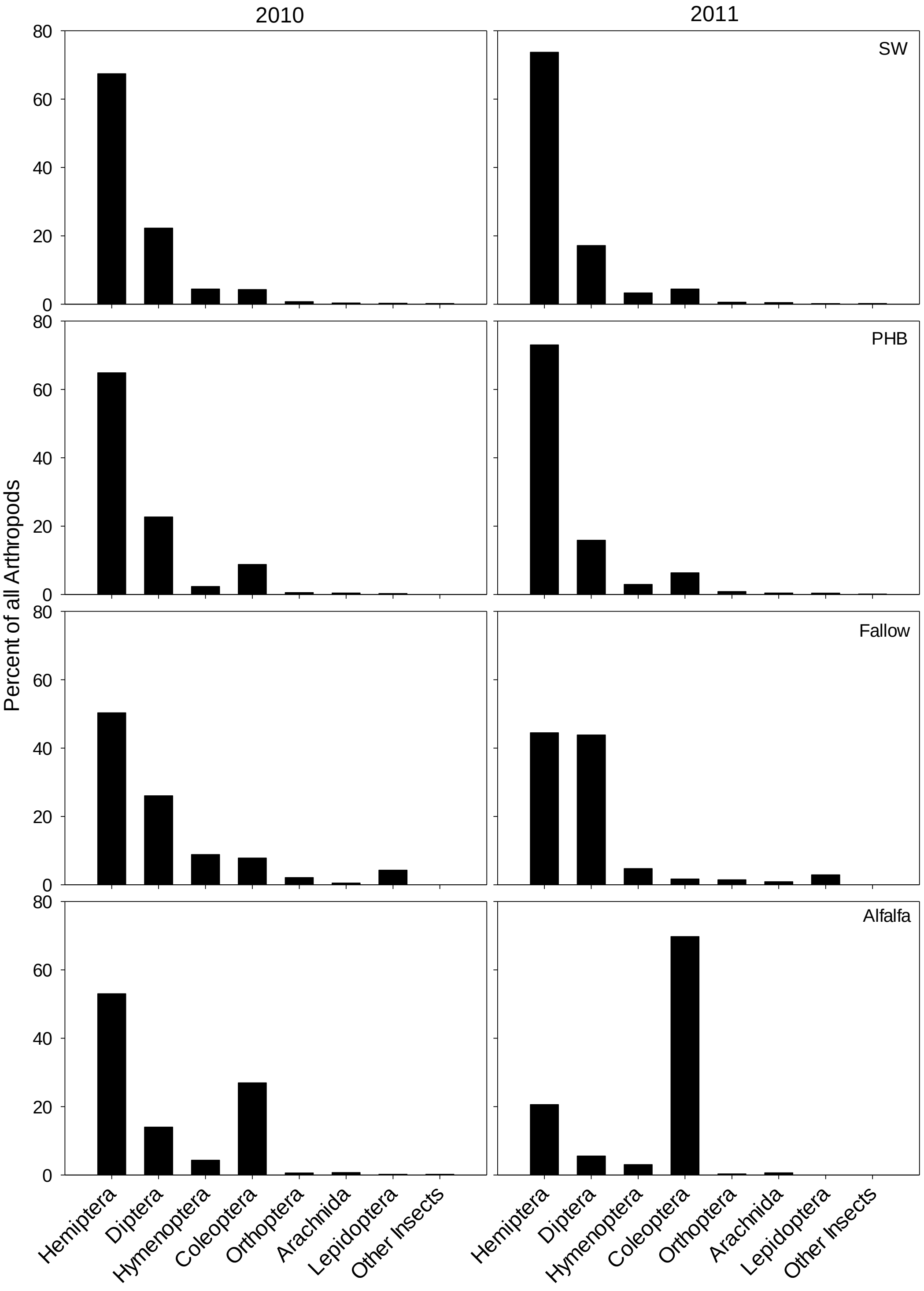


Figure 7: Abundance of insect families at Fort Ellis, both years. Order of taxa in all plots is based on their rank order of abundance in the spring wheat plots in 2010. All families were present in each habitat in each year, at least in low numbers.

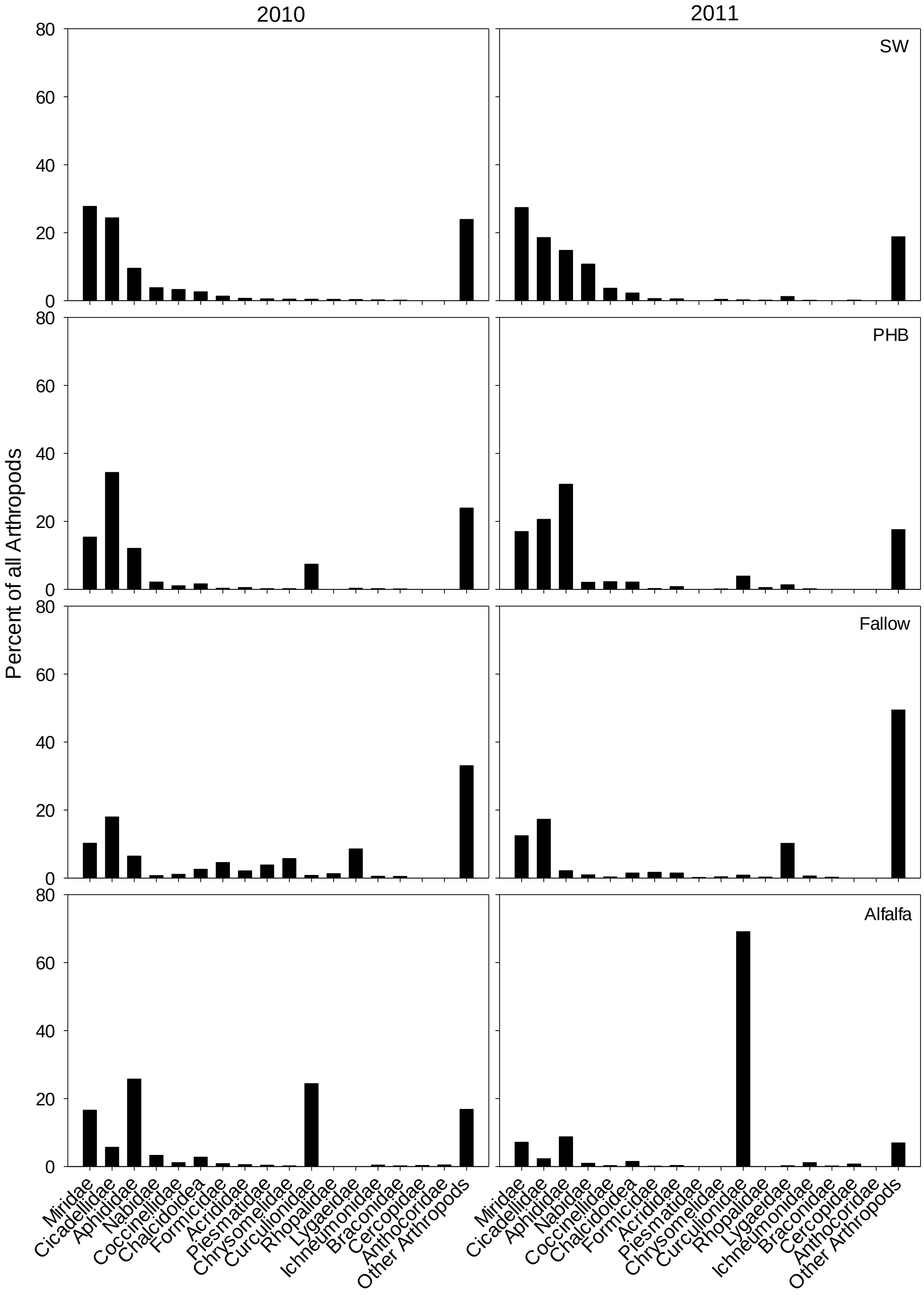


Figure 8: Temporal trends of average total arthropod abundance according to habitat plots in 2010 and 2011.

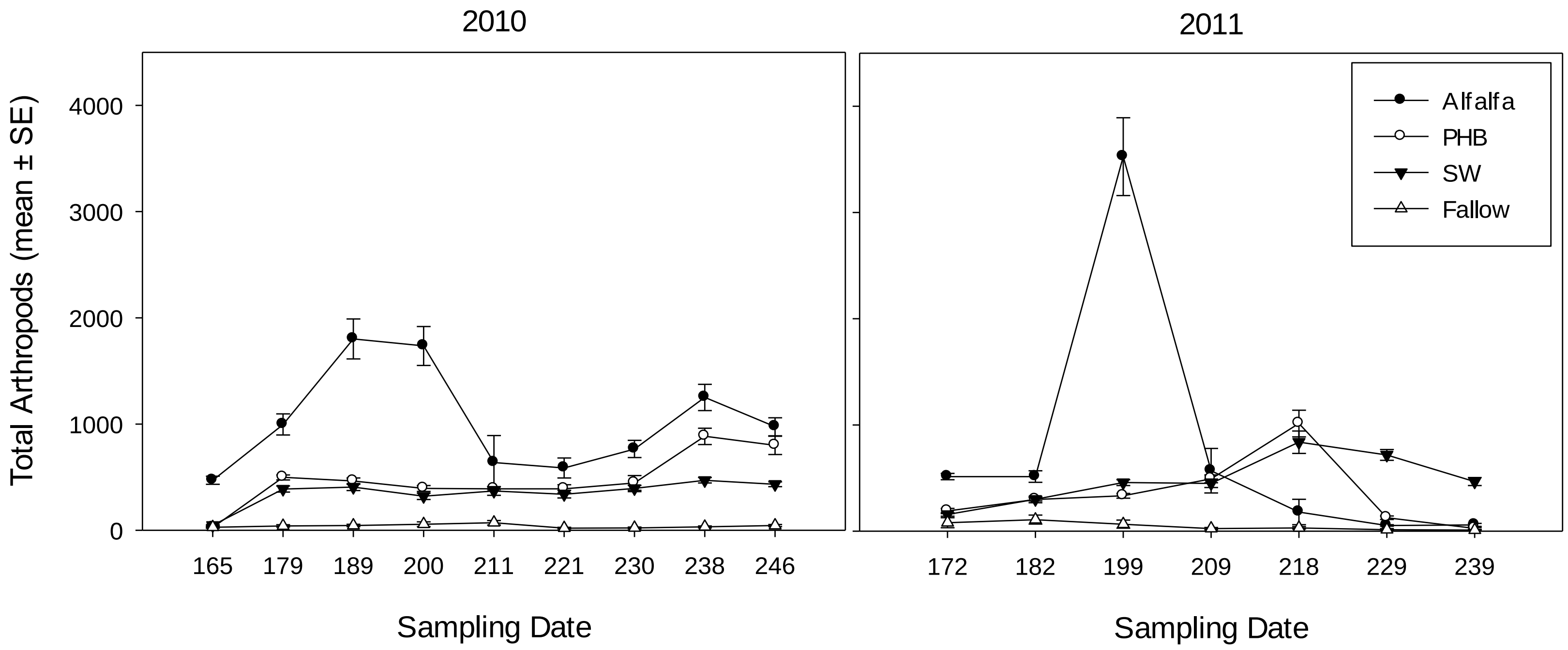
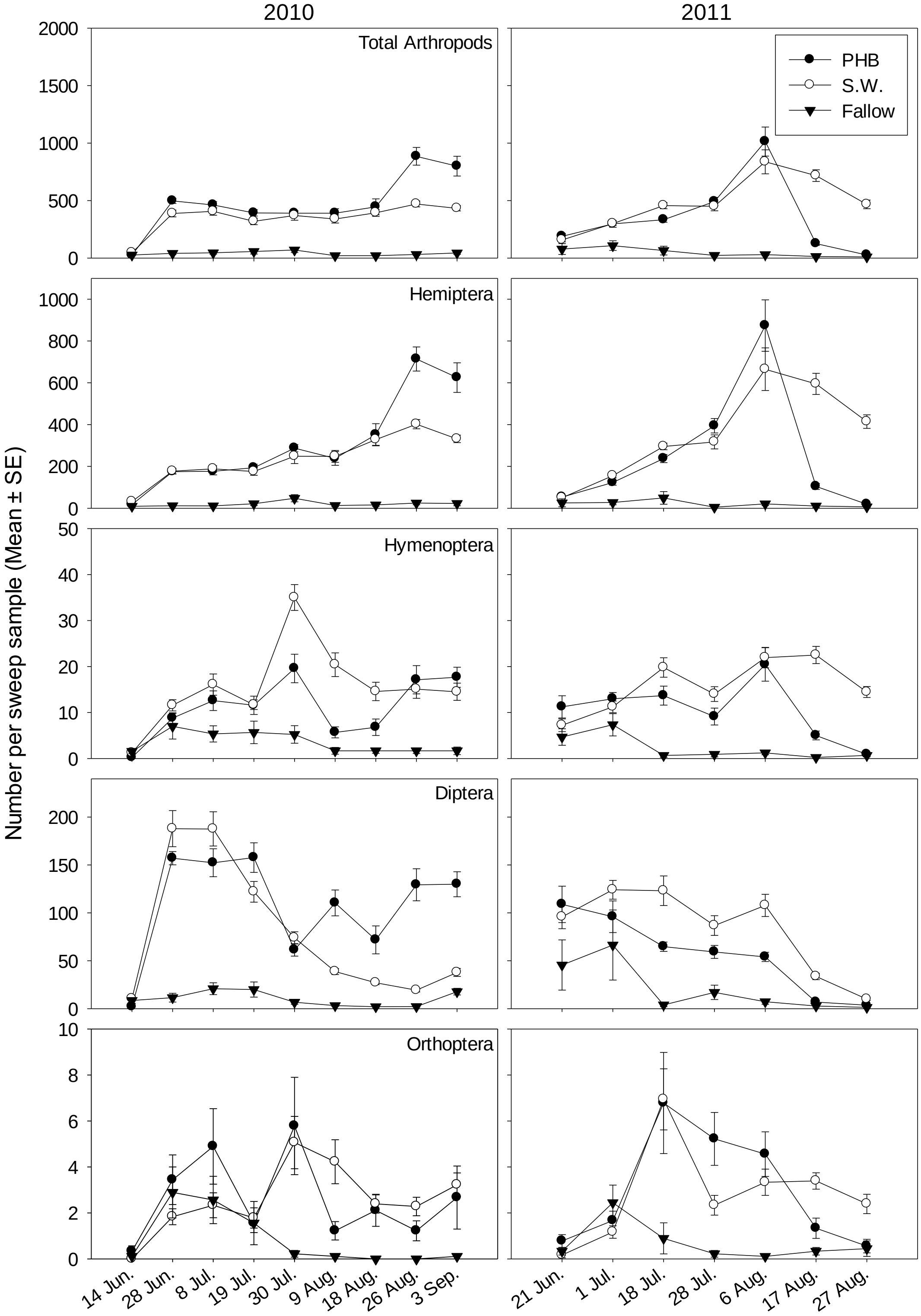


Figure 9: Temporal trends in numbers of individuals of major orders of insects and arachnids (Araneae and Opiliones) at Fort Ellis (2010-2011).



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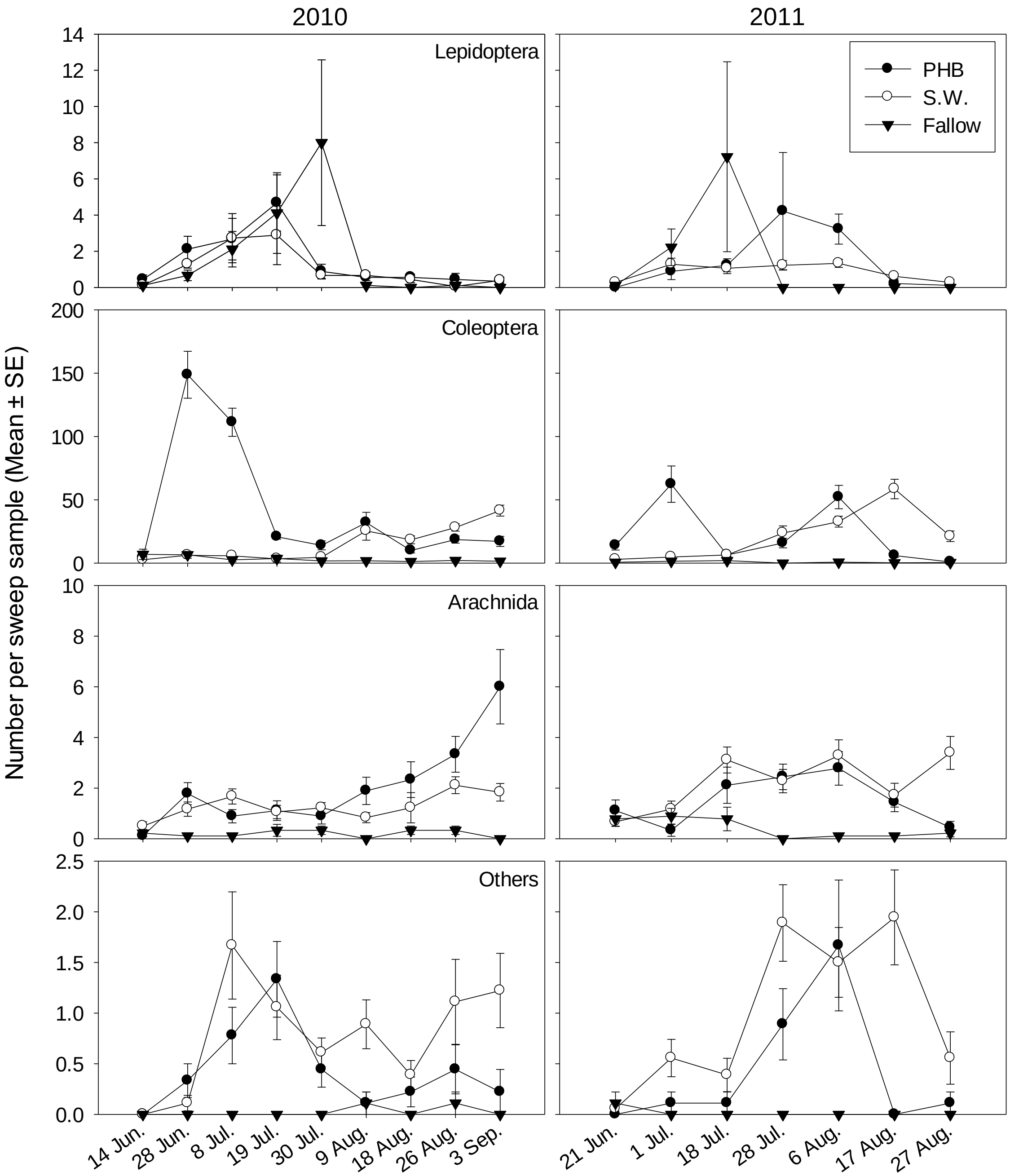


Figure 10: Temporal trends in numbers of individuals of major families of insects at Fort Ellis (2010-2011).

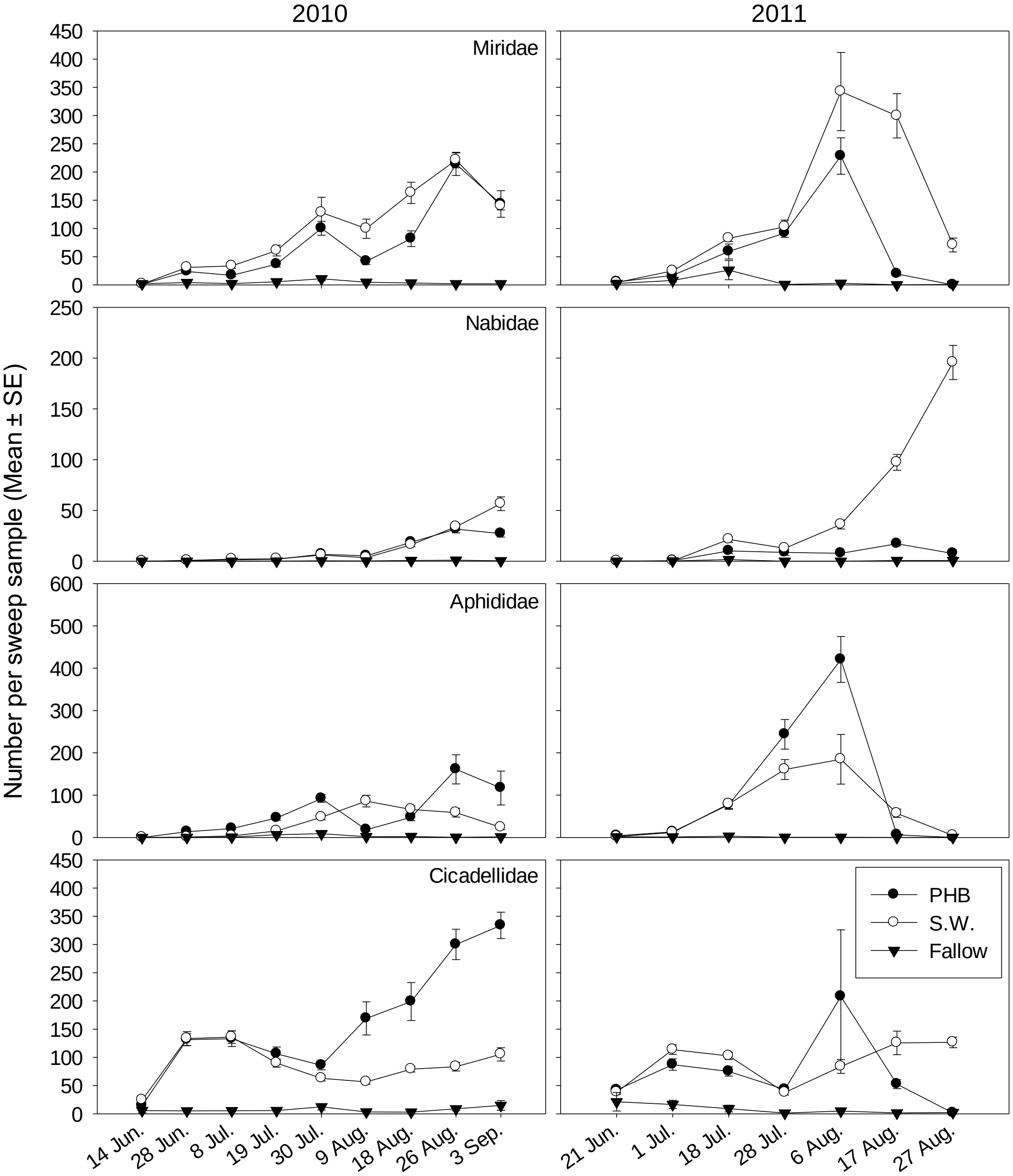


Figure 11: Temporal trends in numbers of individuals of major orders of insects and arachnids (Araneae and Opiliones) in the spring wheat plots (2010-2011).

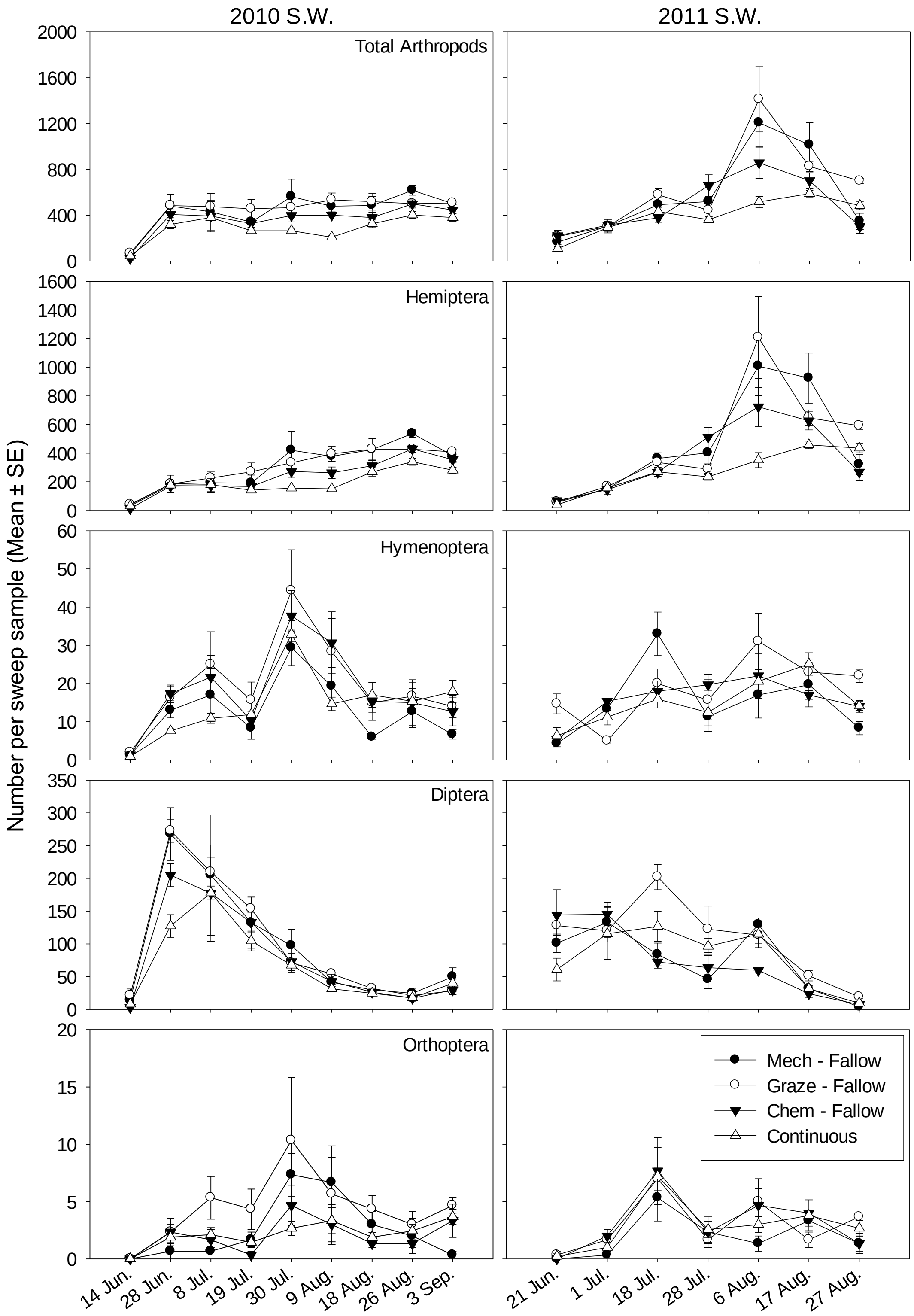


Figure 11 Continued

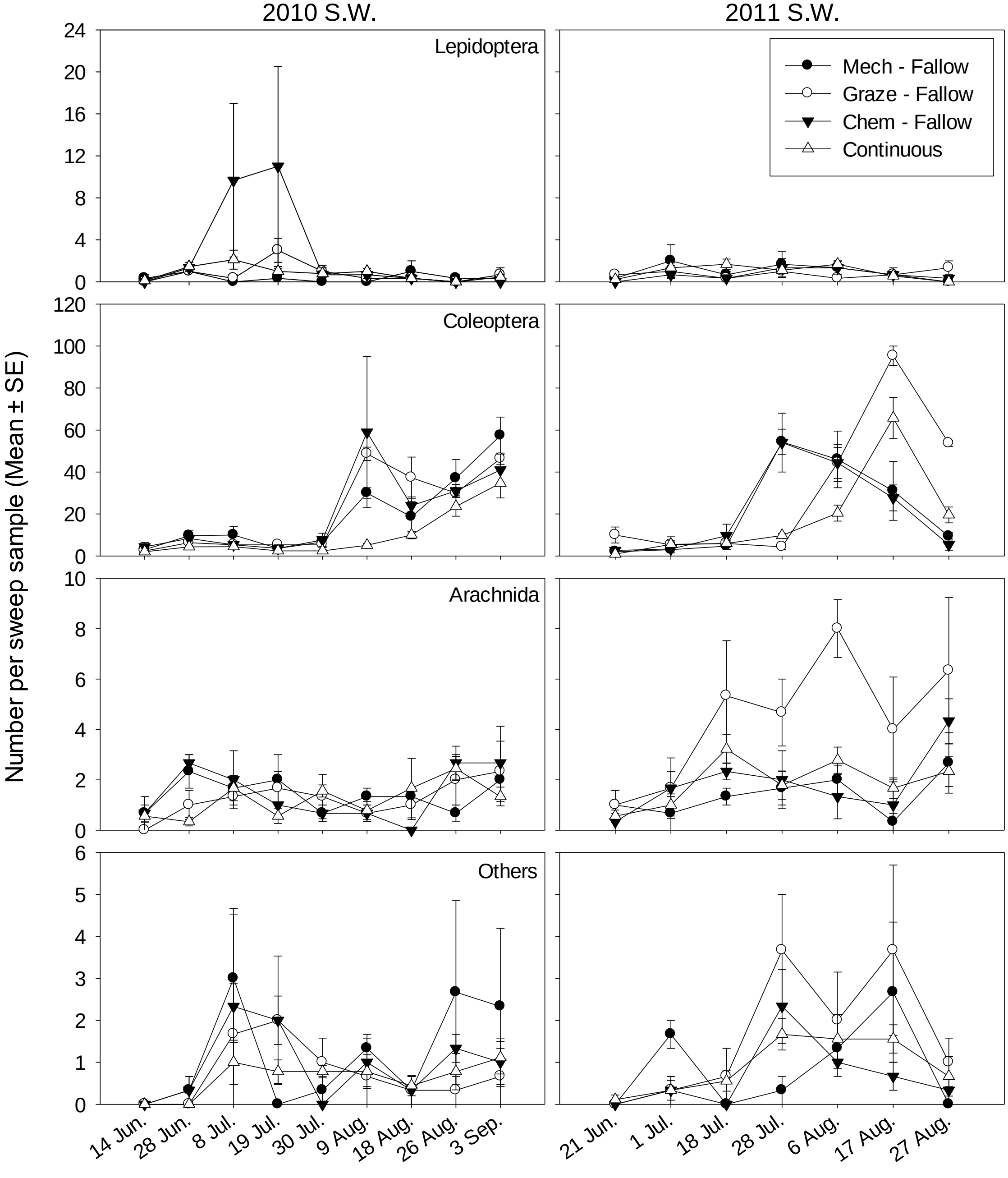


Figure 12: Temporal trends in numbers of individuals of major families of insects in the spring wheat plots (2010-2011).

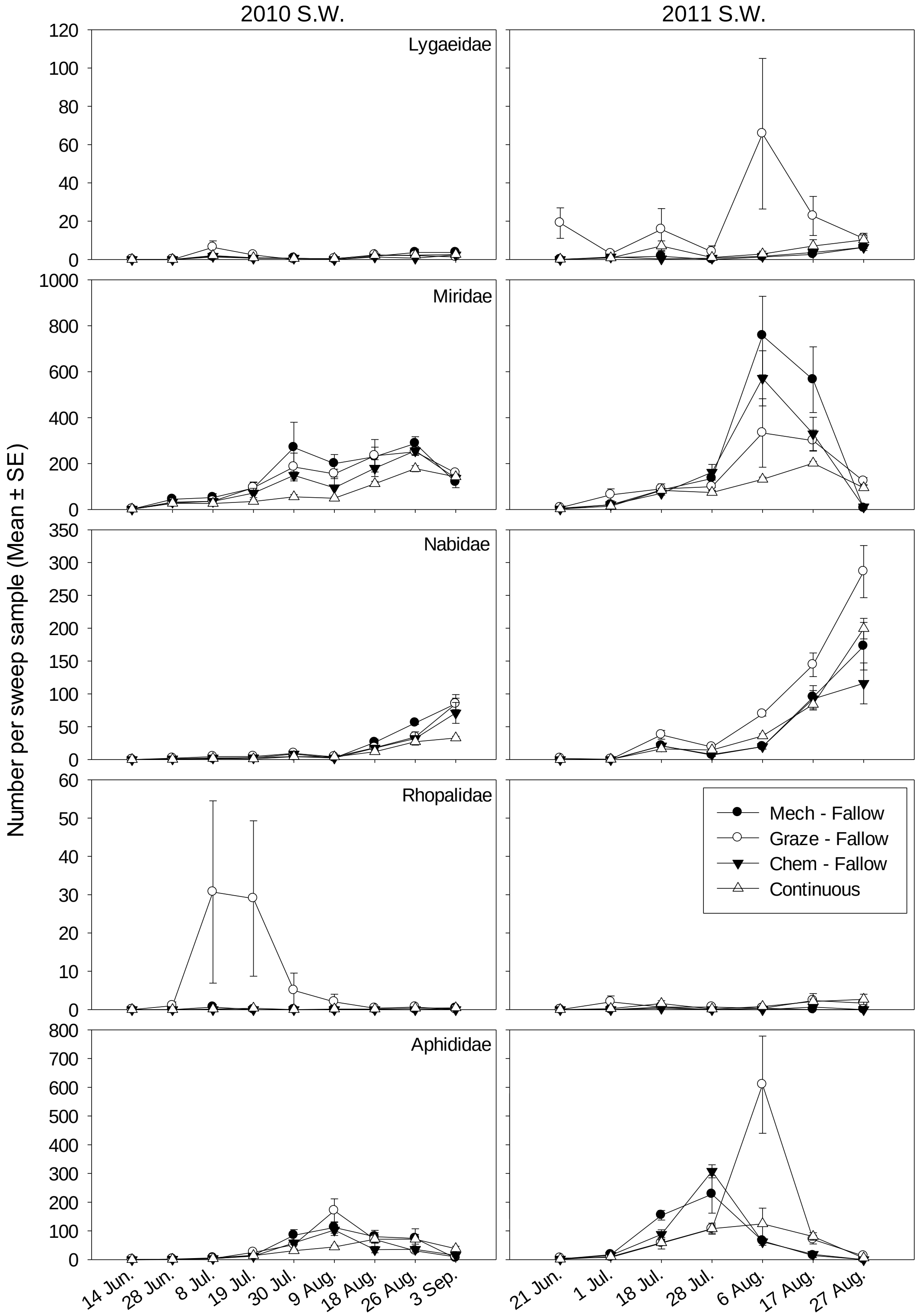


Figure 12 Continued

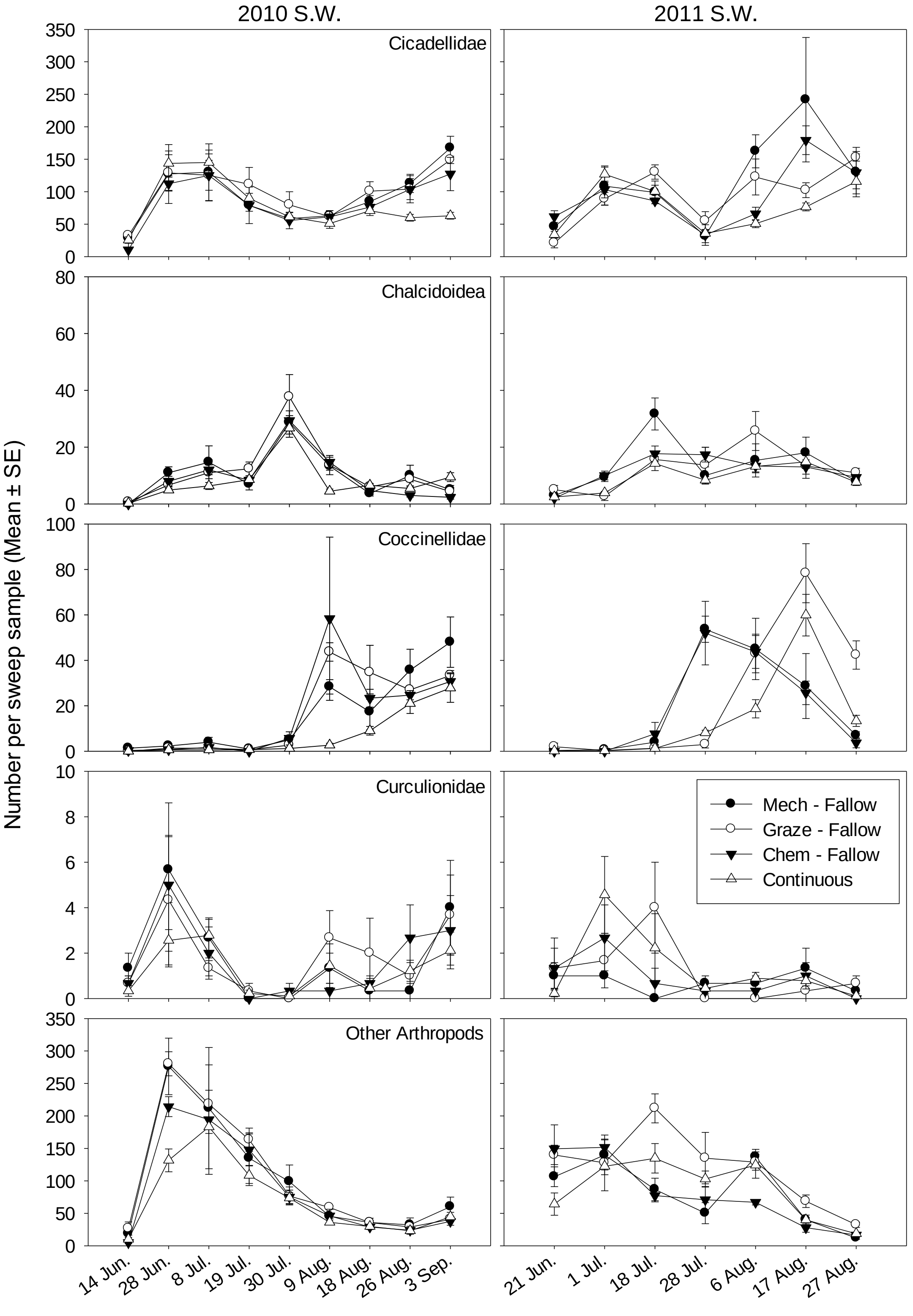


Figure 13: Temporal trends in numbers of individuals of major orders of insects and arachnids (Araneae and Opiliones) in the pea/hay barley plots (2010-2011).

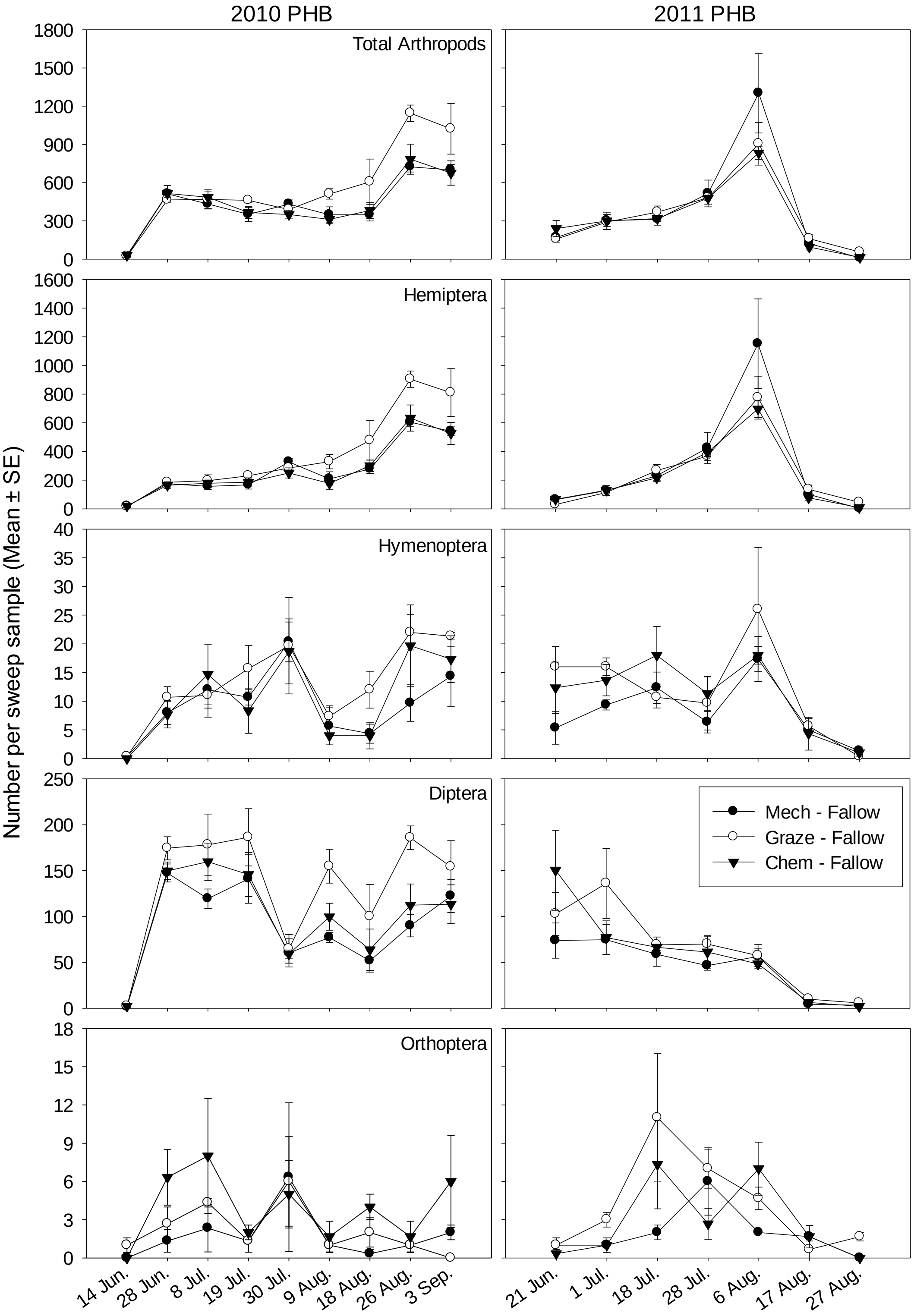


Figure 13 Continued

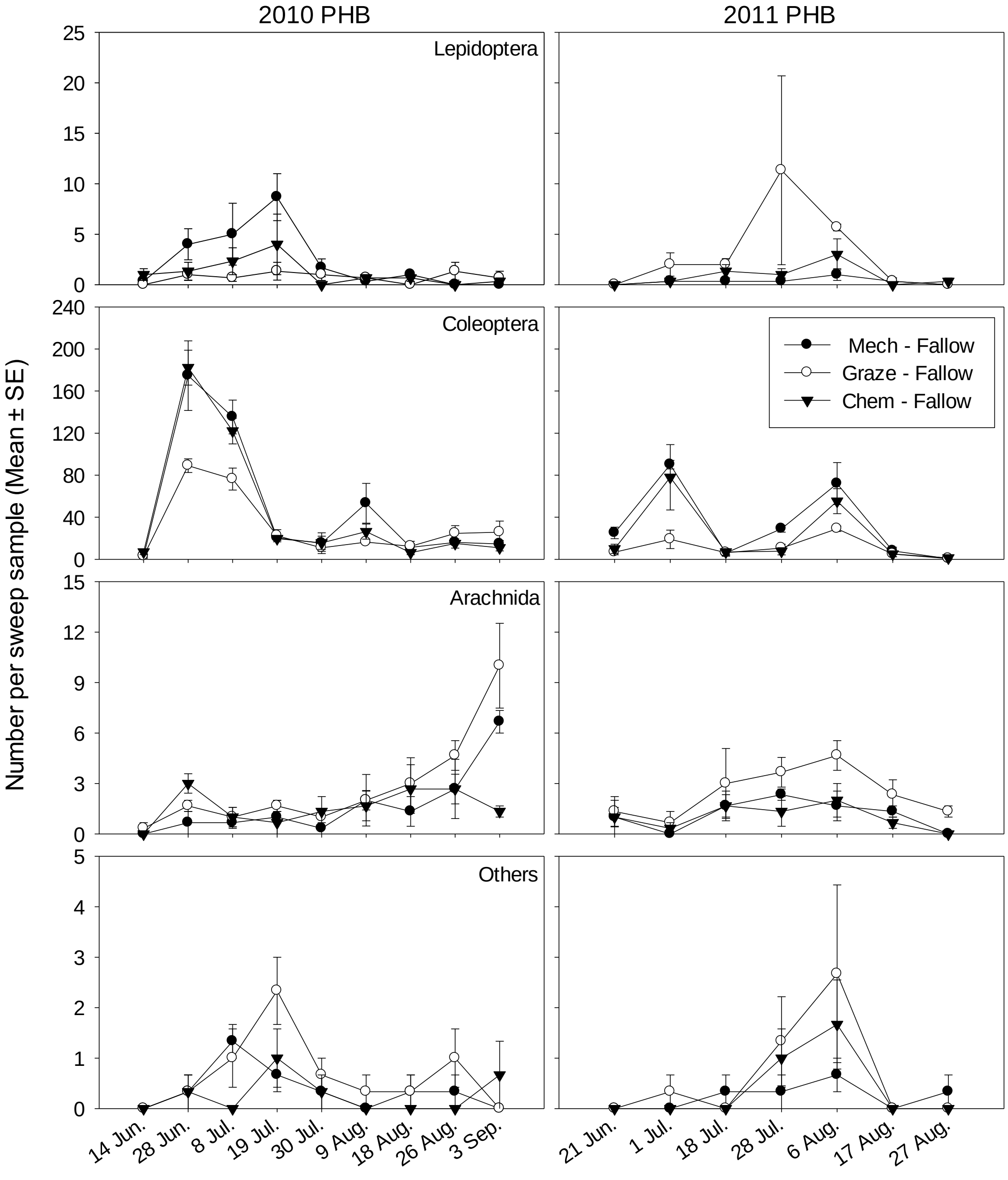


Figure 14: Temporal trends in numbers of individuals of major families of insects in the pea/hay barley plots (2010-2011).

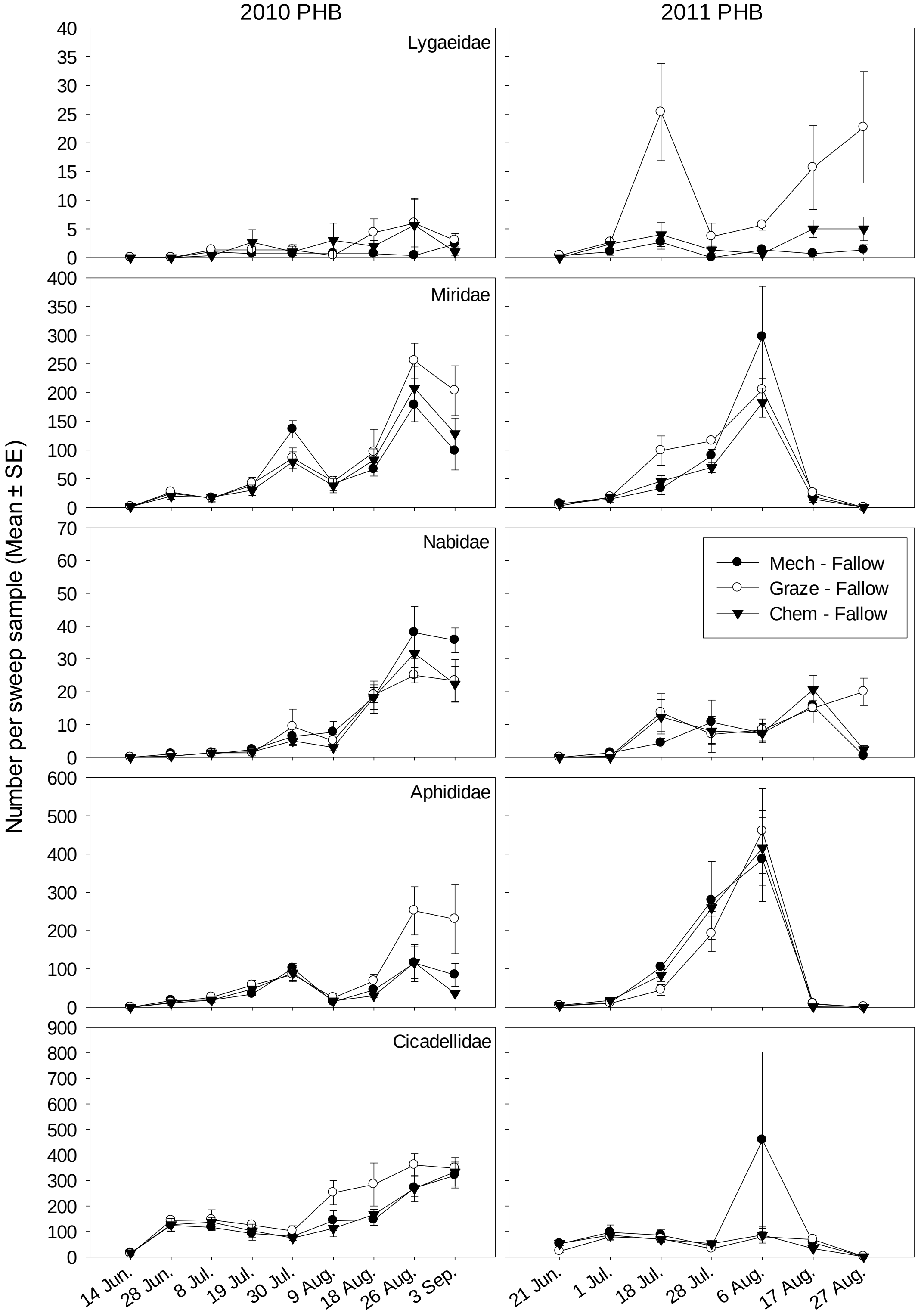


Figure 14 Continued

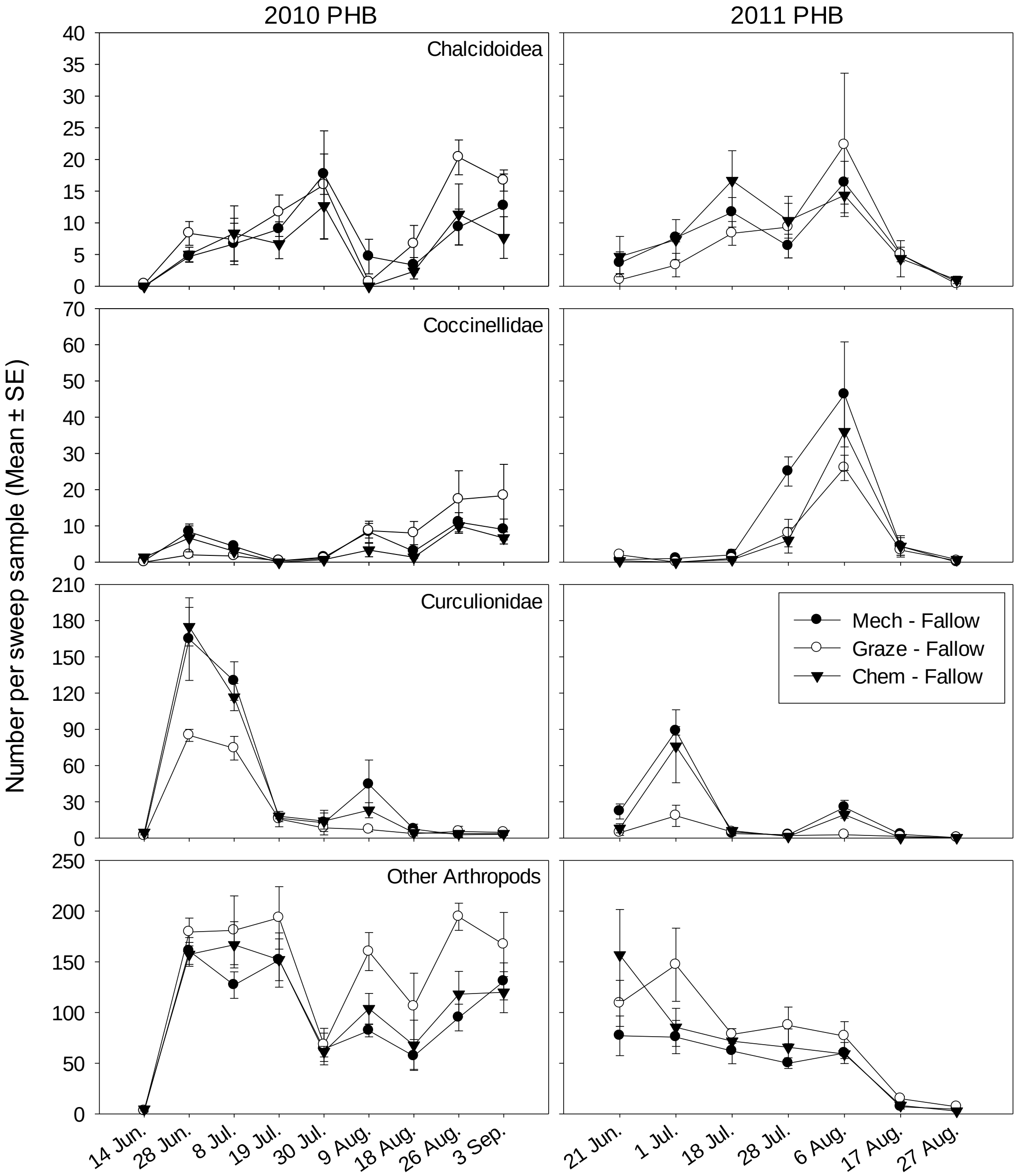
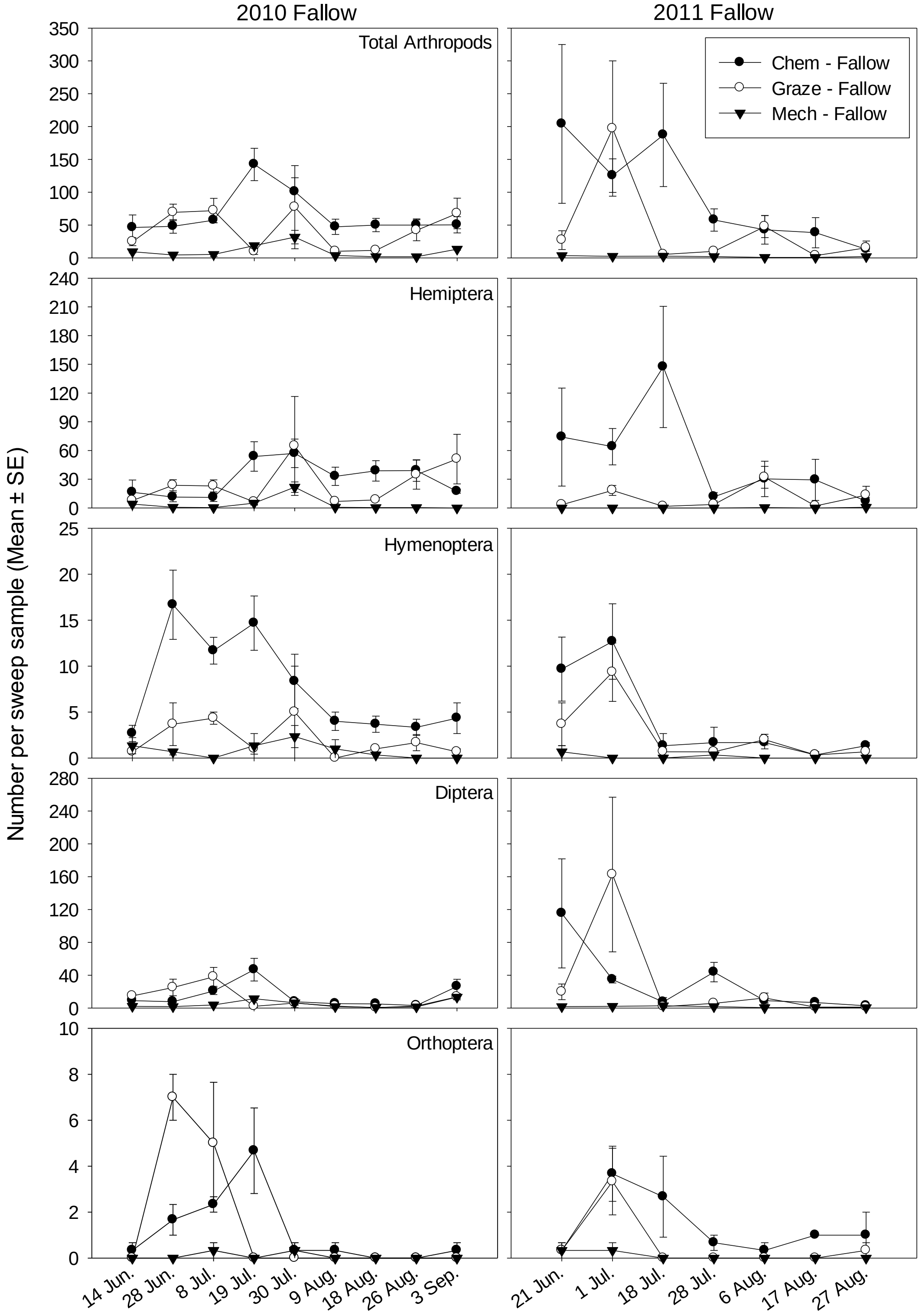


Figure 15: Temporal trends in numbers of individuals of major orders of insects and arachnids (Araneae and Opiliones) in the summer fallow plots (2010-2011).



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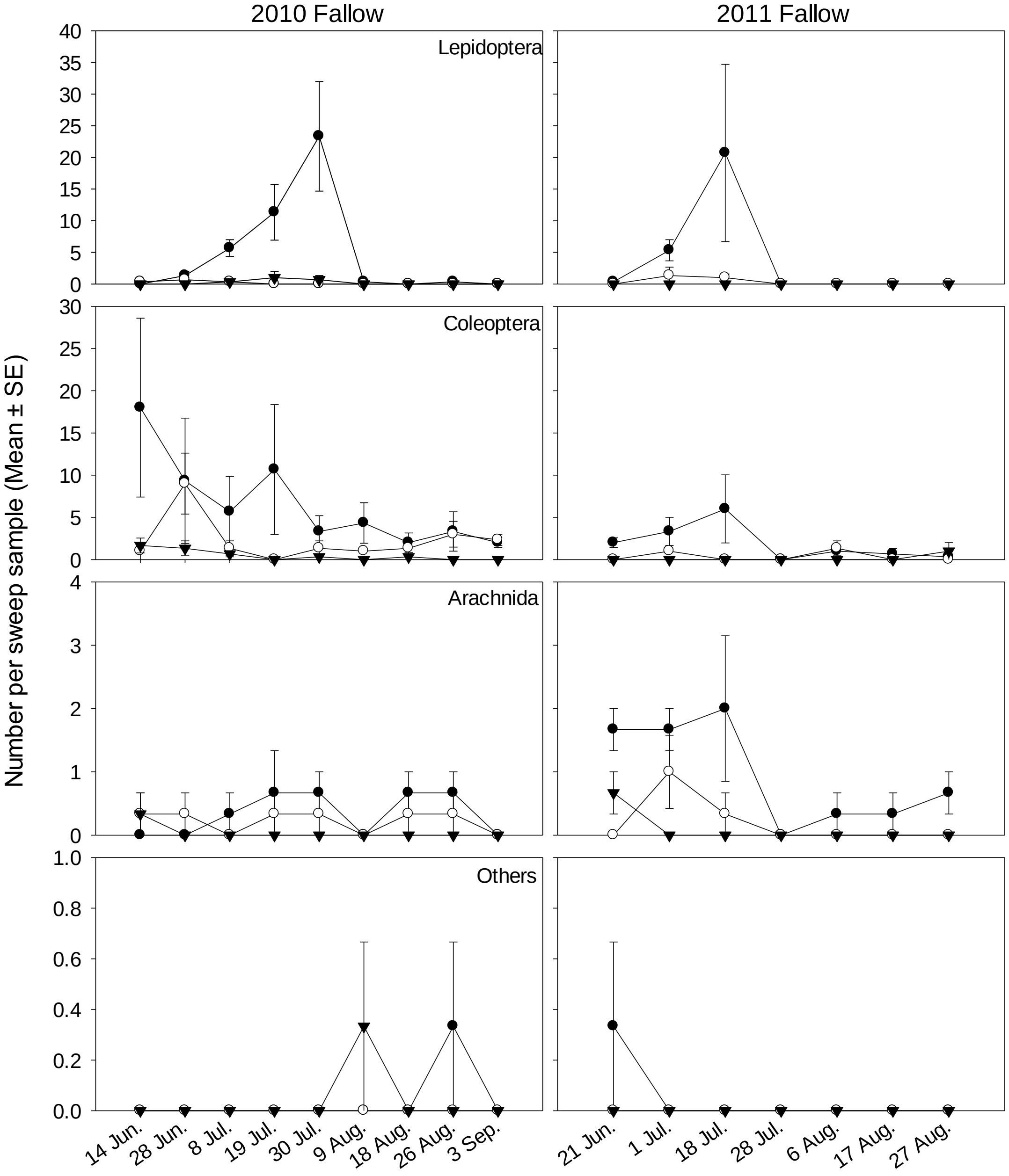
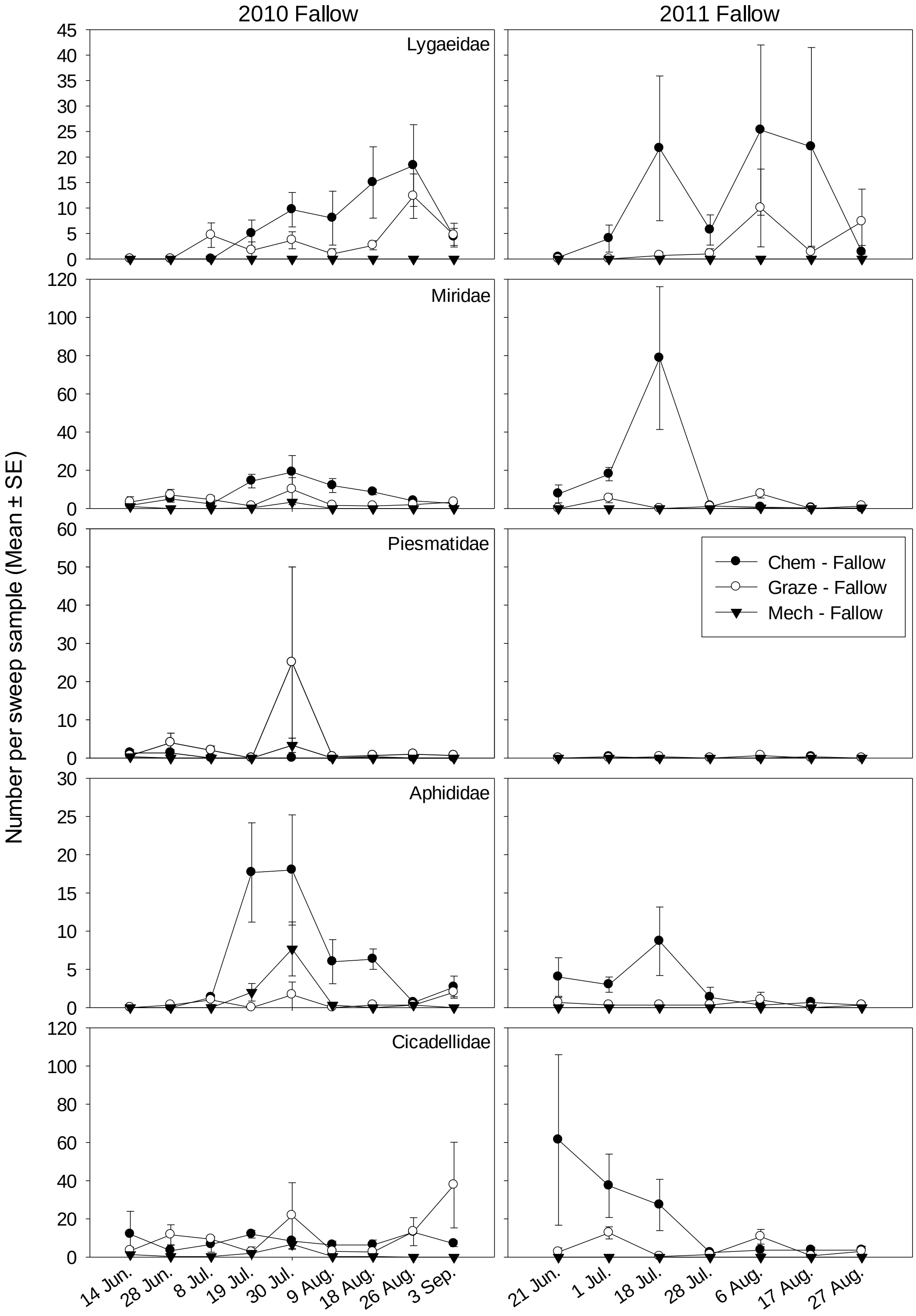


Figure 16: Temporal trends in numbers of individuals of major families of insects in the summer fallow plots (2010-2011).



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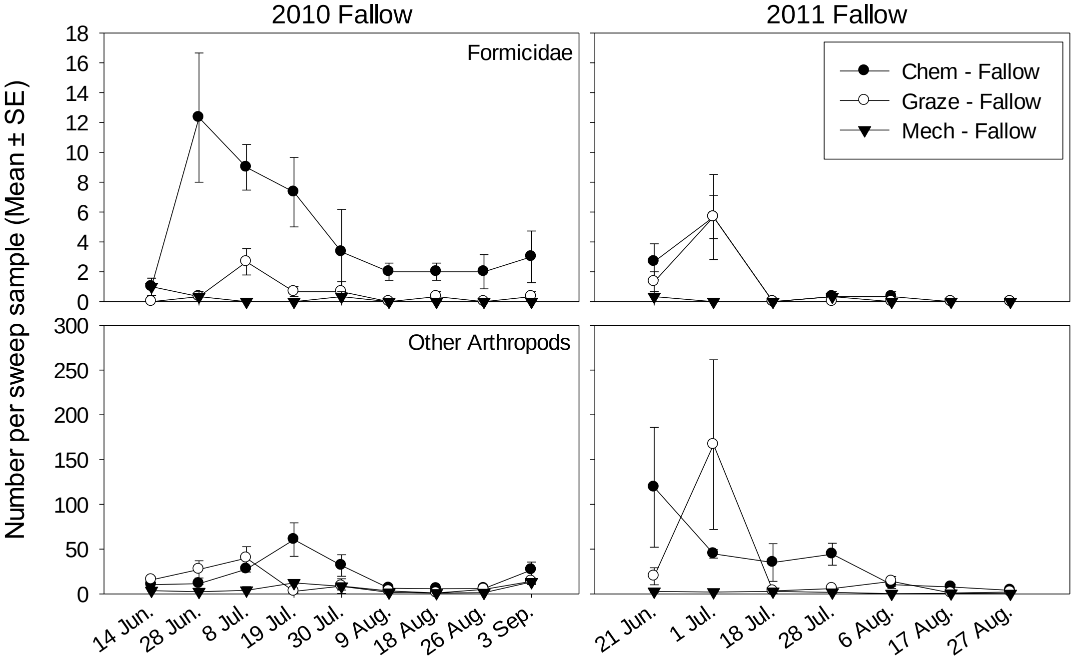


Figure 17: Temporal trends in numbers of individuals of major orders of insects and arachnids (Araneae and Opiliones) in the alfalfa plots (2010-2011).

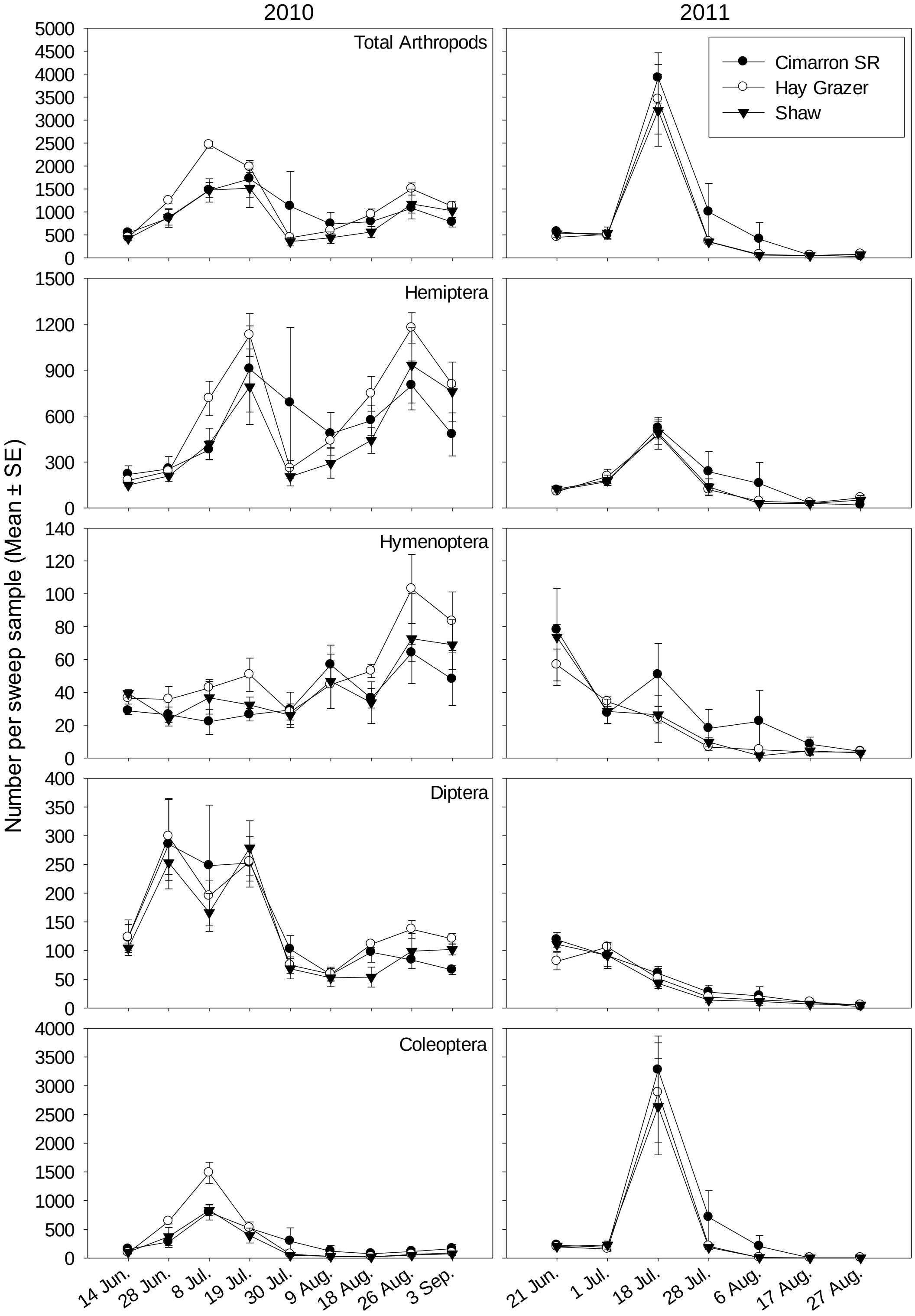
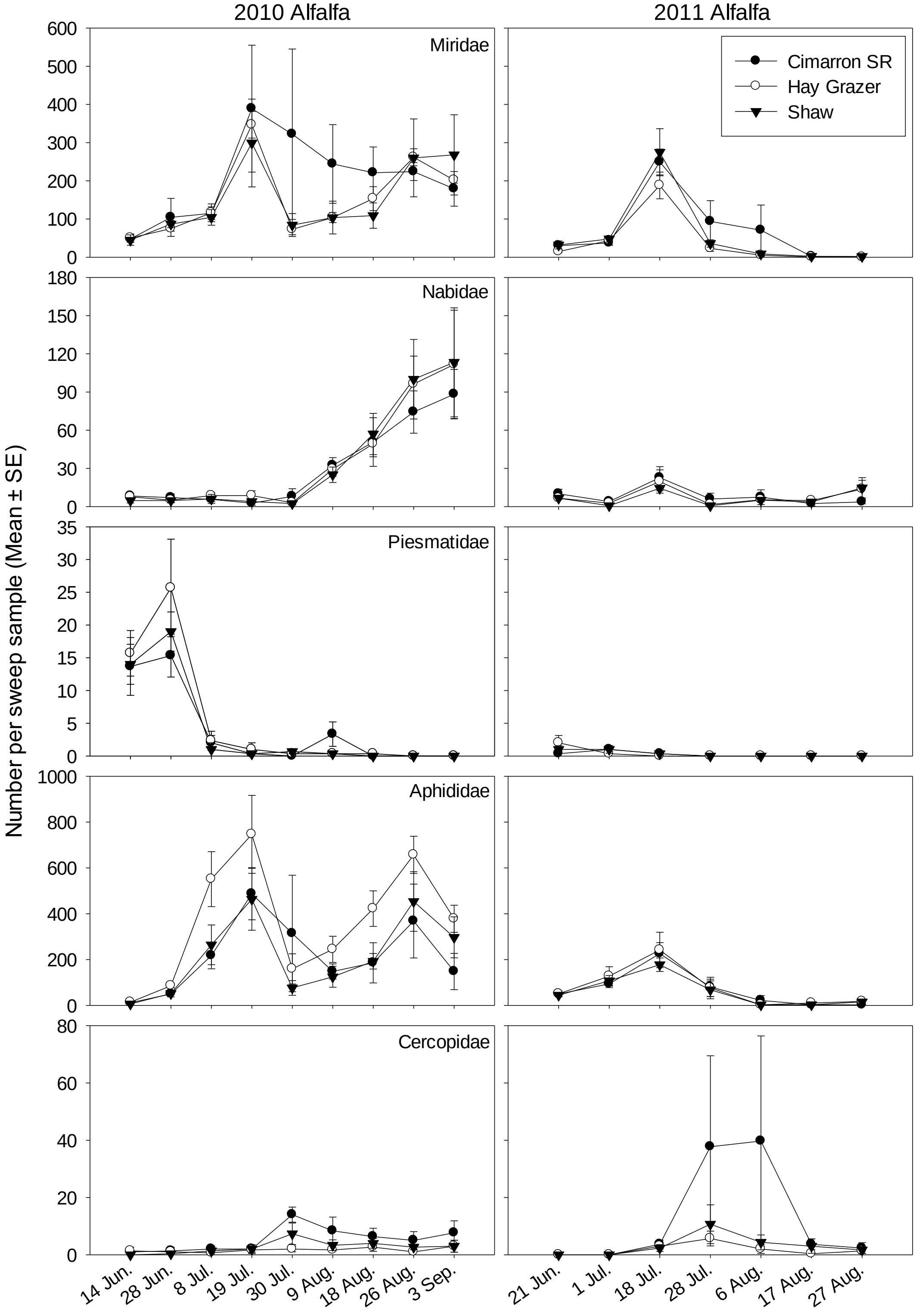


Figure 18: Temporal trends in numbers of individuals of major families of insects in the alfalfa plots (2010-2011).



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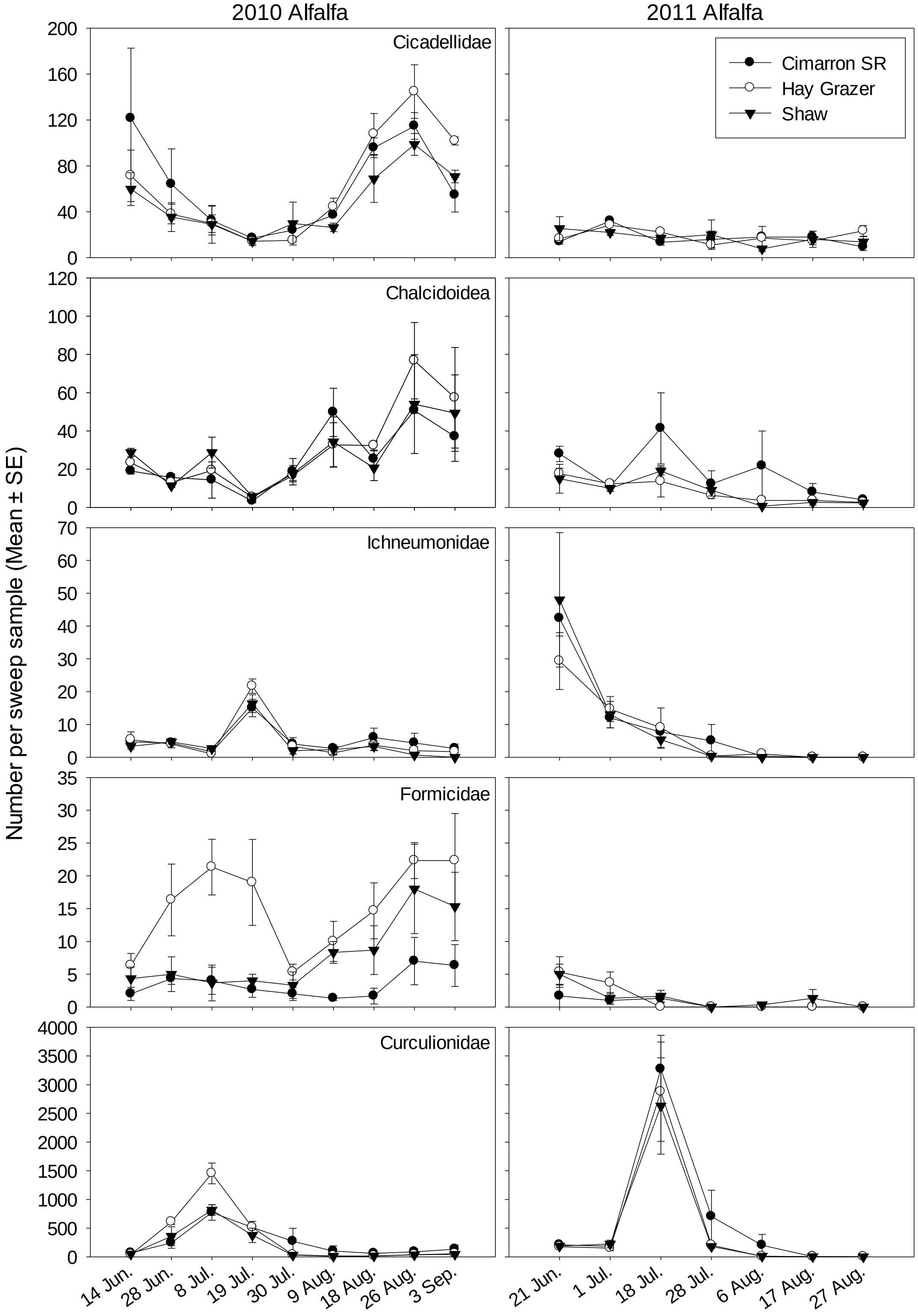


Figure 19: Proportions of wireworms by species collected in Fort Ellis, both years.

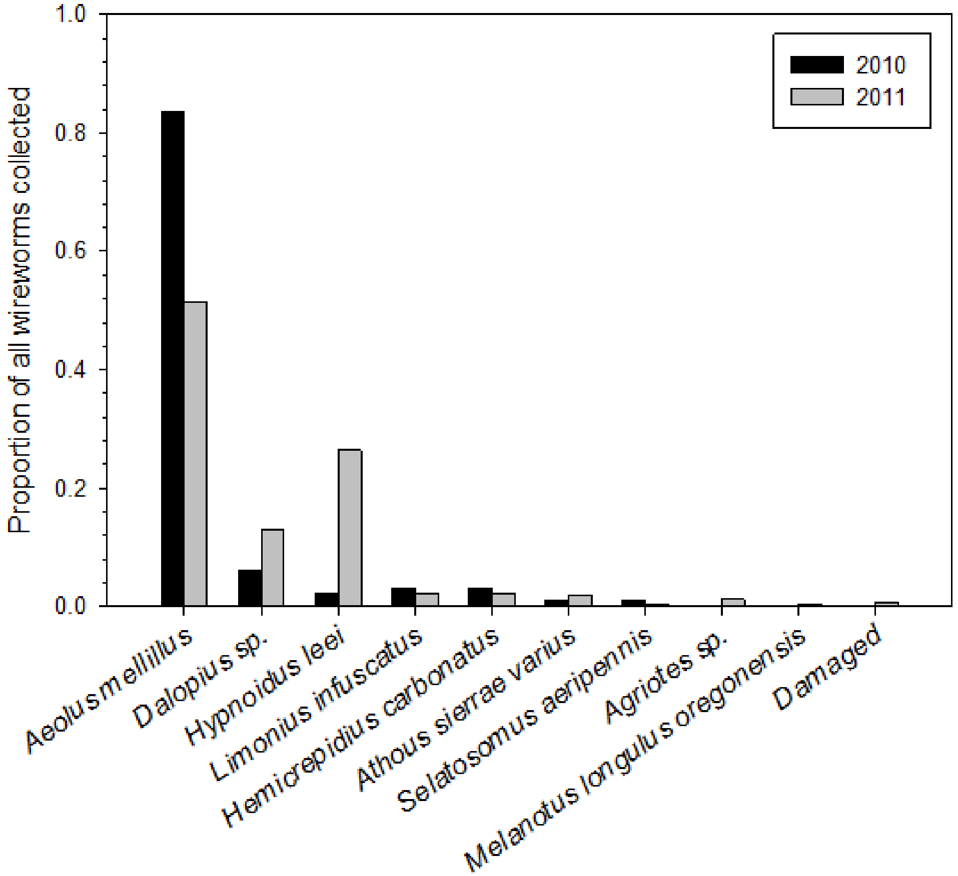


Figure 20: Mean of wireworm abundance in the alfalfa, rotational, and continuous spring wheat for 2010 and 2011.

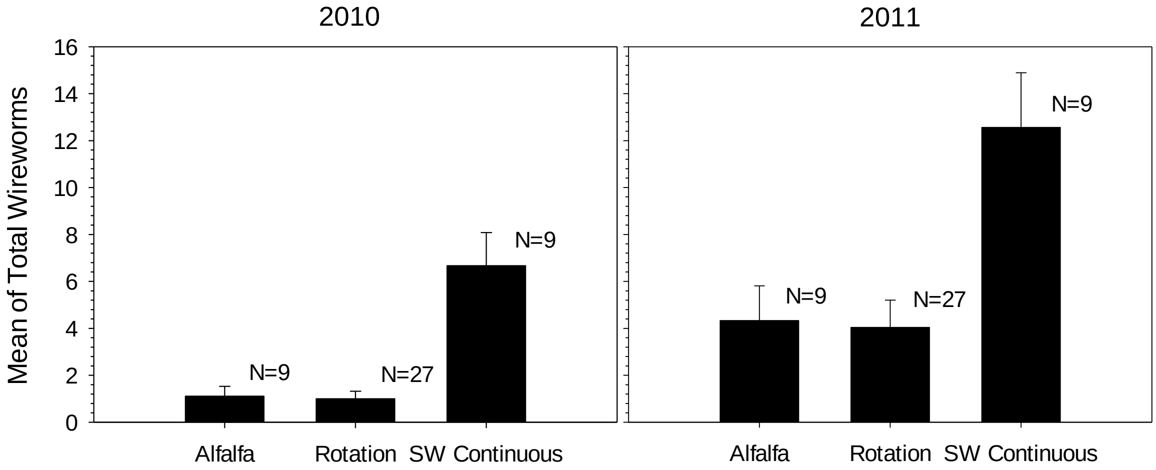


Figure 21: Mean of wireworm abundance in the alfalfa, fallow, pea/hay barley, rotational, and continuous spring wheat for 2010 and 2011.

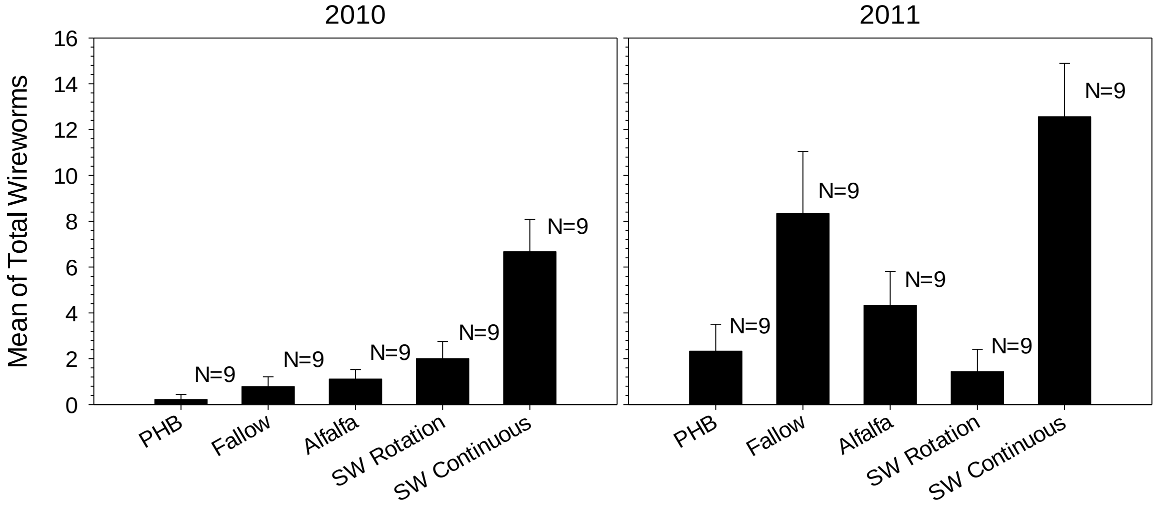


Figure 22: Mean of wireworm abundance in the three alfalfa cultivar plots in both years.

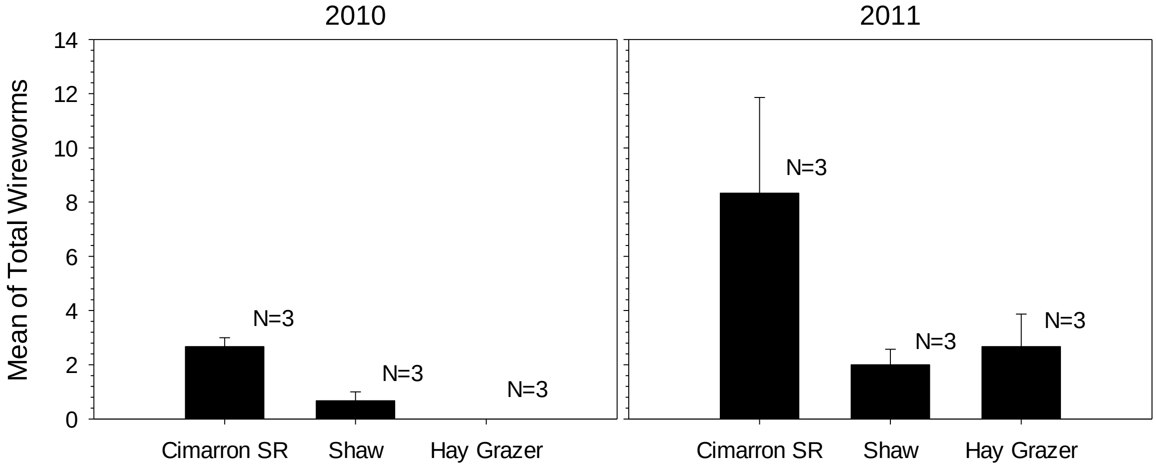


Figure 23: Mean of wireworm abundance in the three management treatment plots for 2010 and 2011.

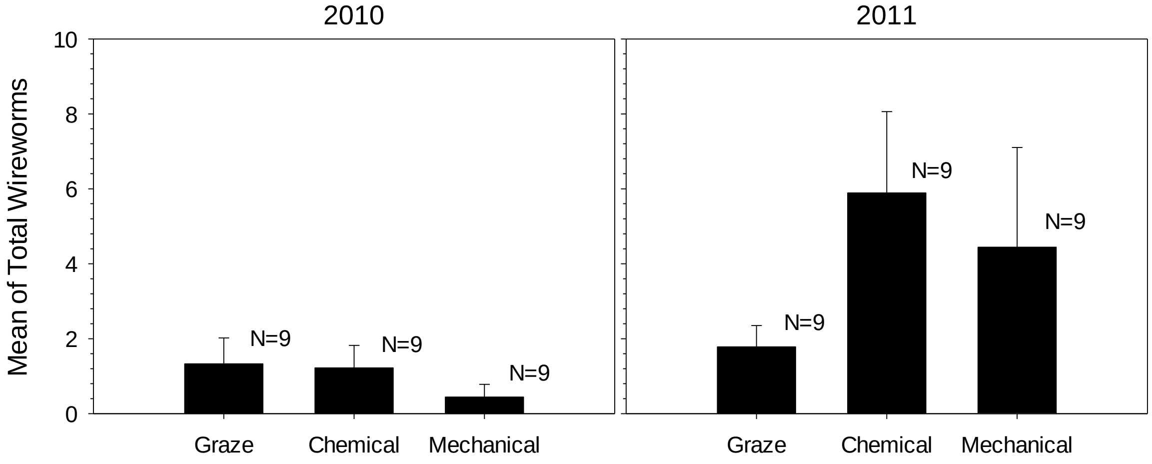


Figure 24: Mean of *A. mellilus* wireworms in the alfalfa, rotational, and continuous spring wheat for 2010 and 2011.

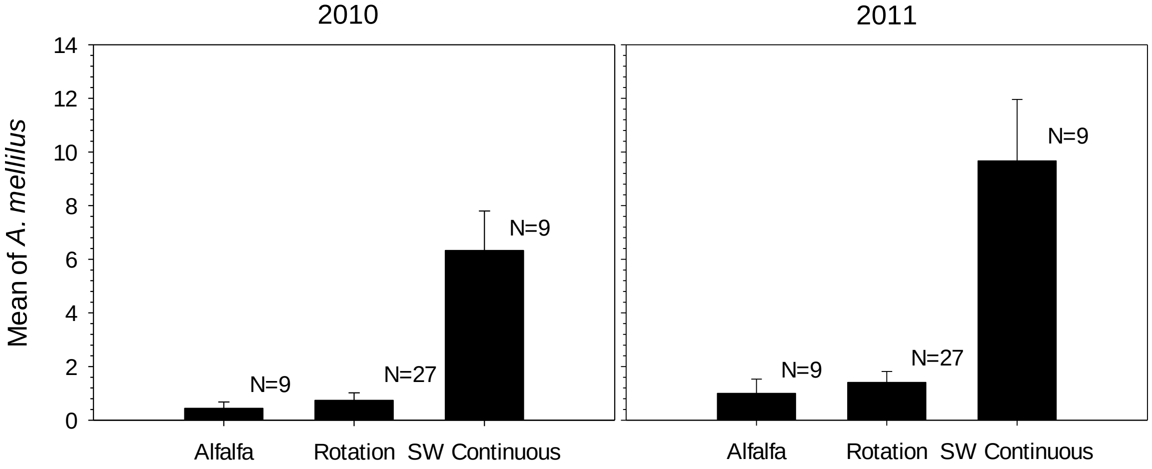


Figure 25: Mean of *Dalopius* sp. wireworms in the alfalfa, rotational, and continuous spring wheat for 2010 and 2011.

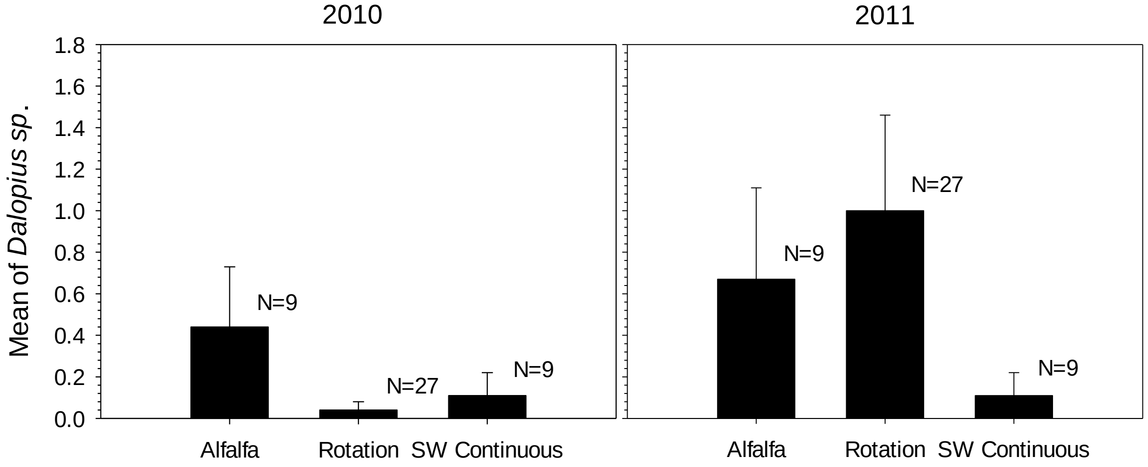


Figure 26: Mean of *H. leei* wireworms in the alfalfa, rotational, and continuous spring wheat for 2010 and 2011.

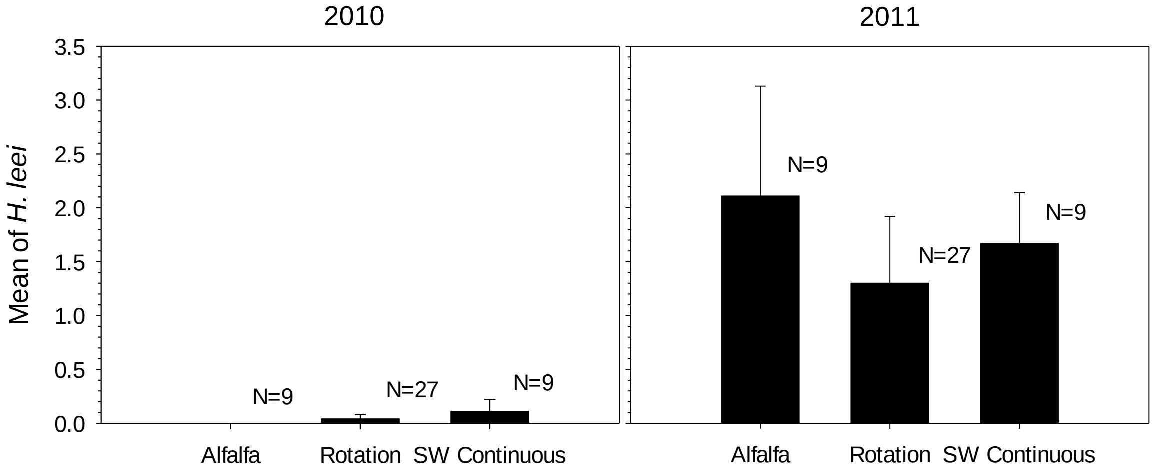
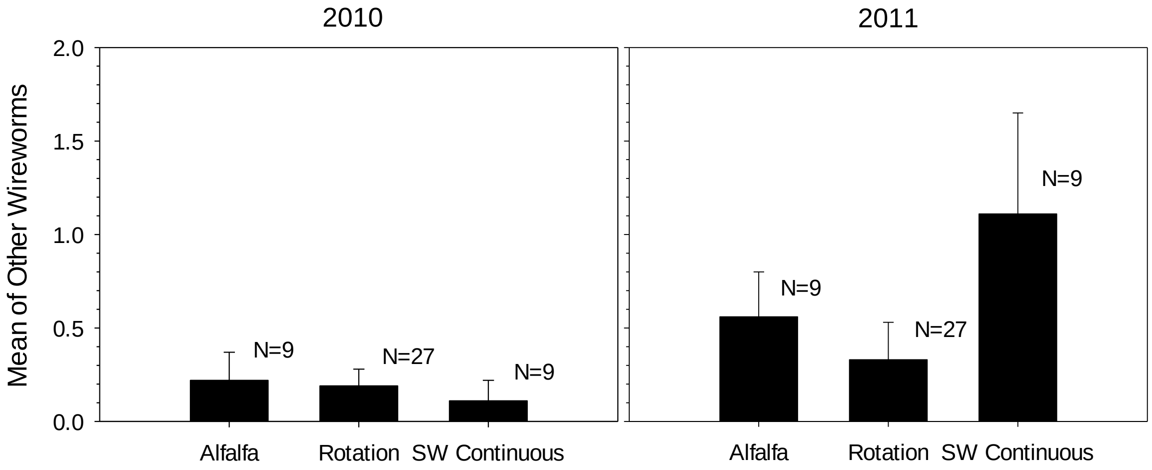


Figure 27: Mean of other wireworm species in the alfalfa, rotational, and continuous spring wheat for 2010 and 2011.



DISCUSSION

Spring Wheat

Crop rotation is one of the oldest and most effective cultural control methods practiced globally to reduce pest and disease outbreaks while maintaining the soil water and fertility content in agricultural fields (Bullock, 1992). By alternating crops cultivated from one year to the other, the normal life cycle of insect pests is interrupted when placed in the subsequent crop which is non-host habitat. When dealing with a reoccurring pest species known to have a narrow host range, selecting a suitable crop rotation plan can sometimes prove to be the simplest solution (All, 1989).

In our study, rotational spring wheat was incorporated into a three-year rotational plan that also included hay barley interseeded with pea and a fallow period. The rotational spring wheat was also subjected to three different treatments (it was planted in plots where the previous year fallow was managed under chemical, grazing, and mechanical treatments) and compared to the continuous spring wheat.

Major insects pests found abundantly present on the spring wheat plots were leafhoppers (Cicadellidae), pea aphid (*A. pisum*), spotted alfalfa aphid (*T. maculata*), and leaf bug (*Trigonotylus* spp.). In 2010, total arthropod abundance was the highest in the grazing and mechanically treated rotational spring wheat. The total arthropod abundance in the chemically treated rotational spring wheat did not differ from the continuous spring wheat which shows that the effect of rotational treatments (continuous and rotational spring wheat) depended upon management treatments (chemical, grazing, and mechanical). The total abundance of hemipterans, cicadellids, and dipterans showed a similar effect as the total arthropod abundance. Hemipterans were found to be most common in the grazed rotational spring wheat plots and lowest in the mechanically treated continuous spring wheat plots. Cicadellids and Diptera were more common in the grazing and mechanical rotational spring wheat plots. The plant bugs (Miridae) were affected independently (no interaction) by rotational treatments (continuous and rotational spring wheat) and management treatments (chemical, grazing, and mechanical). They were more abundant in the rotational spring wheat plots than in continuous spring wheat plots. Within the rotational spring wheat plots, fewer plant bugs were found in the chemically-treated plots than the mechanically-treated plots and grazed plots showed no difference in plant bug numbers when compared to the two other treatments. Leaf bugs (*Trigonotylus* spp.) had a similar effect as the mirids but were most common in the grazed and mechanical rotational spring wheat plots and lowest in the chemical and mechanical spring wheat plots. The damsel bugs (nabids) and lady bugs (coccinellids) which are both important natural enemies were only affected by the rotational treatments (continuous and rotational spring wheat) and were more common the rotational spring wheat plots.

Treatment effects on insect abundances varied between years. In 2011, the only factor that affected the total arthropod abundance was the rotational treatments (continuous and rotational spring wheat), and there were more arthropods present in the rotational spring wheat plots compared to continuous spring wheat plots. Hemiptera, mirids, *Trigonotylus* spp., cicadellids, chalcids, and coccinellids were all more abundant in the in the rotational spring wheat plots compared to continuous spring wheat plots. Aphids and Diptera were most common in the grazed rotational spring wheat plots. Management treatments (chemical, grazing, and mechanical) depending upon the rotational treatments (continuous and rotational spring wheat) affected the total number of damsel bugs or nabids.

The general trend observed was that the rotational spring wheat plots harbored more arthropods than the continuous spring wheat plots. Despite the popular belief that crop rotation reduces the buildup of pests, continuous wheat monoculture is highly stable with regards to pest infestations (Hill, 2008). Previous studies have shown that continuous wheat monoculture often had lower insect pest infestations and decreases were observed in multivoltine (having multiple generations per year) insect species which were either oligophagous or polyphagous. Since several of the multivoltine polyphagous insects rely on different hosts to complete their life cycle, they shift to different hosts between generations. When monoculture becomes prevalent, the alternate hosts are diminished. This interrupts the normal life cycle of the multivoltine polyphagous insects which ultimately leads to their population decline (Andow, 1983).

Pea/Hay Barley

Hay barley interseeded with pea was one of the rotational phases for the three-year rotation in our study. The practice of incorporating pea/hay barley into the rotational plan that also includes spring wheat and fallow helps in conserving the soil-water content (Lenssen et al., 2010). Apart from allowing more water available to subsequent crops, peas are legumes that aid in replenishing the soil nitrogen content which then reduces the need for nitrogen fertilizer.

Major insects pests collected from the pea/hay barley plots were leafhoppers (Cicadellidae), two mirids (*Trigonotylus* spp. and *Lygus* spp.), alfalfa root weevil (*S. discoideus*), pea aphid (*A. pisum*), and spotted alfalfa aphid (*T. maculata*). In 2010, the highest arthropod abundance in pea/hay barley was in the grazed managed plots. Beneficial arthropods such as the arachnids (predators), dipterans (mostly predators and pollinators), and chalcids (predators) were more common in the grazed fallow pea/hay barley plots. This could have been due to the high numbers of herbivores such as aphids and *Trigonotylus* spp. which were also found in higher proportions on the grazed fallow pea/hay barley plots compared to the chemical and mechanical fallow pea/hay barley plots. Curculionids (weevils) which were mostly alfalfa root weevil were least common in the grazed plots than in the chemically- and mechanically-treated pea/hay barley plots. In 2011, however, the three fallow treatments did not have any effect on total arthropod abundance. Predators such as arachnids and nabids were found to be more common in the grazed fallow pea/hay barley plots which could have been due to high numbers of herbivores (lepidopterans, lygaeids, and *Lygus* spp.). Alfalfa root weevils were once again least common in the grazed plots than in the chemically- and mechanically-treated pea/hay barley plots.

Alfalfa root weevils, like many other *Sitona* weevil species, are pest of legumes (Bright, 1994 and McKirdy et al., 2008). Female weevils lay their eggs from spring to autumn on the soil surface near host plants. The first-instar larvae emerge and start to feed on the root nodules first and then moving to rootlets and root hairs of host plants (Aeschlimann, 1986). Aeschlimann (1986) stated that “hatching during the first two months of the oviposition period are most important in terms of population dynamics”. Thus, allowing sheep to graze before planting could have an adverse effect on the population of alfalfa root weevil in the grazing-managed pea/hay barley plots.

Summer Fallow

The practice of keeping the cropland uncultivated during regular growing seasons which is also known as fallow allows the soil to regain its moisture and fertility and thus improving the crop yield in subsequent years. Weeds that might otherwise disrupt the resting period of the land are controlled by means of tillage and herbicide applications. Arthropods being harbored by weeds could also become a problem to growers as some of them are generalist feeders which could shift their feeding from weeds to crop plants (Capinera 2005).

However, mechanical tilling and herbicide applications to control weeds are expensive which could increase the cost of dryland grain production (Goosey et al., 2005). Recently, alternatives such as allowing ruminants such as sheep and goats to graze on summer fallow fields are being proposed as a tactic that could keep fallow weed management costs down.

In this study, the effectiveness of sheep grazing as a fallow weed management tactic was compared to the more common management practices of applying tillage (mechanical) and herbicides (chemical). In both years, arthropods were consistently the lowest in abundance in the summer fallow plots which were mechanically tilled while the sheep grazed and chemically-treated fallow showed no difference in their total arthropod abundance and that there was an interaction between date and treatment effects.

By mechanically tilling the soil, weeds which mostly have shallow root systems are uprooted and killed. Because the weeds that serve as refuge to the above ground arthropods die shortly after being uprooted, arthropod numbers will begin to dwindle quickly. With the applications of chemical herbicides, however, the weeds are not killed instantly. Because most of the arthropods are not directly affected by the herbicides, they could remain on the weeds until it is no longer suitable for them as a refuge. It has been observed in some instances that herbicide-stressed weeds further suffered from higher rates of herbivory as the populations of phytophagous arthropods increased (Pimentel, 2002).

Grazing by sheep removes the above-ground plant foliage that serves as a refuge and food for arthropod pests, though removal of weeds may also decrease nectar sources and host prey for beneficial arthropods (Russell, 1989 and Southwood, 1986). Although most of the studies involving grazing as a method to manage pests were conducted on grassland and mostly focused on rangeland pests such as grasshoppers (Onsager, 2000, O'Neill et al., 2003, 2008, and 2010), the results show that there were reduction of insect pests after grazing. Spring alfalfa grazing by cattle in Georgia caused a reduction in weevil larvae numbers by 65% in 'Alphagraze' alfalfa and by 32% in 'Apollo' alfalfa (Buntin & Bouton, 1996). In Montana, sheep grazing either in winter or spring wheat resulted in increased mortality of overwintering wheat stem sawfly larvae (Goosey et al., 2005, Hatfield et al., 2007).

Alfalfa

Alfalfa, which is worth $7 billion annually in the United States, occupies about 2.5% of the agricultural land (USDA, National Agricultural Statistical Service, 2007). Montana has larger alfalfa acreage compared to any of the western U.S. states (Putnam et al., 2000). With all the available cultivars in the market today, selecting the best cultivar has become a priority. Cash et al. (1993) suggest that selection of cultivars should be made based on features such as winter hardiness, yield potential, pest resistance, persistence, forage quality, and availability.

Because the alfalfa weevil is the most economically damaging insect pest of alfalfa in the United States (Blodgett et al., 2000), choosing a cultivar with good resistance against alfalfa weevil is highly recommended. However, most of the available cultivars today are only partially resistant to the alfalfa weevil and rarely provide adequate protection against the weevil, especially larval infestations which inflict the most damage (Blodgett et al., 2000).

The three commercially available cultivars grown at our experimental station were Cimarron SR, HayGrazer, and Shaw. According to alfalfa seed companies such as Cimarron USA and Delange Seed, the Cimarron SR and HayGrazer cultivars are supposedly tolerant to the alfalfa weevil (http://cimarronusa.com and http://www.delangeseed.com/alfalfa.htm). The Shaw cultivar which was made available by Montana State University, is a dryland cultivar with high yields and no current tolerance ratings against insect pests.

Alfalfa feeding insects that we collected at our study sites included the alfalfa weevil (*H. postica*), alfalfa root weevil (*S. discoideus*), pea aphid (*A. pisum*), spotted alfalfa aphid (*T. maculata*), two mirids (*Adelphocoris* spp. and *Lygus* spp.), and leafhoppers (Cicadellidae). The abundance of alfalfa weevil and most other herbivores did not differ among the three cultivars in either 2010 or 2011. The exception was aphids (*A. pisum* and *T. maculata* combined), which were more abundant in the HayGrazer in 2010. Beneficial insects such as the ants were also more abundant in the HayGrazer and the ichneumonids were more common in both the Cimarron SR and HayGrazer cultivars in 2010.

In 2011, all of the alfalfa plots experienced a large infestation of alfalfa weevil larvae. The average number of larvae collected per plot during the peak of the infestation (July 18th) was 2931 (i.e., 58/sweep), which was almost three times higher compared to an average of 1038 larvae per plot (21/sweep) during the peak of the infestation in 2010 (July 8th). Because the economic threshold for the alfalfa weevil is 20 larvae per sweep (Peairs et al., 2011), the infestation level in 2011 was three times the economic threshold. The damage caused was so severe that all of the alfalfa stands were almost completely defoliated. Defoliation by alfalfa weevil larvae combined with a dry year further caused a stunted re-growth in the alfalfa thus reducing the number of insects collected from the alfalfa plots in the later sampling dates. This could explain why the difference in abundance of aphids or other insects was not significant in 2011.

In a ten year study, Busbice (1978) reported that the alfalfa cultivar "Starnes" was tolerant to defoliation caused by alfalfa weevil larvae only when grown in isolation from other cultivars. The tolerance was tested over different localities and years across the United States and was found to be consistent. Since the three different cultivars at our field station were grown in plots adjacent to each other, this could have caused the alfalfa weevils from a less resistant cultivar to migrate into the other cultivars and establishing populations.

Wireworms

Of the 955 species of wireworms in North America (Marske & Ivie, 2003), more than 150 species are found in Montana alone (Seibert, 1993). The larvae (wireworm) of a few species are known to be some of the most economically-destructive soil insect pests. Wireworms are a challenging group to study because 1) they are soil-dwelling, 2) some of them are difficult to identify morphologically, and 3) their species composition can differ in both space and time (Finney, 1946). Therefore, the implementation of proper monitoring program involving wireworm sampling followed by accurate species identification is essentially the most important step in constructing an effective wireworm management strategy. Currently, setting bait traps is the most popular technique used in detecting wireworm populations. It is reported to be highly effective and less labor-intensive compared to the previously common method of taking random soil cores (Simmons et al., 1998).

Although the use of soil-incorporated organochlorine and organophosphate insecticides have been most the effective control measure in reducing wireworm populations, concerns over the long-term environmental impact of these persistent chemicals has led to their complete ban or restricted use in the United States under the Environmental Protection Agency Food Quality Protection Act of 1996 (Willis et al., 2010). The increasing pressure to reduce the dependency on chemical based insecticides has thus prompted the need for alternative control measures.

It is widely accepted that cultural practices such as crop rotation combined with soil tillage and fallow are effective in controlling pest populations. Such management practices affect below-ground insect community composition by changing the available food supply, disrupting the habitat structure (moisture availability and aggregate stability), and interrupting the normal life cycle of insects (All, 1989 and Gupta, 1994). However, since wireworms are polyphagous, there is little known about the effects of crop rotation on their populations (Andrews et al., 2008).

We studied the abundance of wireworms collected through bait traps in an agricultural system involving a crop rotational system (pea/hay barley, spring wheat, and summer fallow) under three summer fallow weed management treatments (chemical herbicide, sheep grazing, and mechanical/ tillage) incorporated into a three-year rotation and continuous cropping (alfalfa and spring wheat).

A total of 405 bait traps from three sampling dates were processed in 2010 and 97 individual wireworms of seven different species were collected. In 2011, with the extra available labor, a total of 1080 bait traps from eight sampling dates were processed and wireworms collected increased to 291 and two additional species were discovered. In both years, the wireworm species composition were consistent with *A. mellilus* being the most abundant species followed by *Dalopius* sp., and *H. leei* and collectively, they consisted of over 90% of wireworms collected each year. It is, however, unwise to assume that the current species composition will remain the same in the future. This is because wireworms, depending on the species, can live in the soil from two to five years before pupating (Andrews et al., 2008) and their spatial and temporal occurrence can be sporadic (Finney, 1946). Hence, continuous monitoring is necessary in maintaining an accurate representation of the wireworm species present at any given area.

Because there was no significant difference in wireworm abundance among the continuous spring wheat subplots under the three main plot factor (chemical, grazing, and mechanical), it was acceptable to group all the continuous spring wheat plots as one for further analysis and the same was repeated when results of comparisons within each phase of the three-year rotation (pea/hay barley, spring wheat, and summer fallow) showed that there was no treatment effect. Wireworms collected from the three alfalfa cultivars (Cimarron SR, Hay Grazer, and Shaw) did not differ significantly and thus they were also combined as a group in further analysis.

In both years, there were more wireworms present in the continuous spring wheat plots compared to alfalfa and the rotational phase plots. This suggests that alfalfa is not a preferred host for wireworms found at our site and the three-year rotational scheme is keeping the wireworm numbers down. In a ten year study (1936-1946) conducted at Prosser, Washington, Gibson et al. (1958) reported that wireworms were most abundant in continuous wheat and potato plots, while lower wireworm numbers were associated with alfalfa, corn, and sugar beet plots. Wireworm numbers were the lowest when a four-year alfalfa rotation was incorporated into the rotational plan, an indication that alfalfa was reducing wireworm numbers. Shirck (1945) also found that alfalfa rotations significantly reduced wireworm populations and in addition to alfalfa being a poor diet for wireworms, he also believes this is because alfalfa has a vigorous root system that keeps the soil dry and compact. Gibson and Shirck both suggested that incorporating alfalfa (for at least half of the time) as a part of a rotational cropping system was an effective cultural control method for wireworms.

Crop rotation combined with soil tillage and fallow can be an effective management practice in reducing wireworm populations in infested fields (Seal et al., 1992, Gibson et al., 1958, and Shirck, 1945). Furlan et al. (2009) asserted that soil from fields grown with continuous crops were more conducive and contributed to higher survival of wireworms. It has been demonstrated that the practice of continuously tilling the soil was effective in lowering the wireworm numbers in infested fields (Seal et al., 1992). Tilling breaks up the soil surface, exposing wireworms located close to the soil surface to predation and to high temperatures that may cause desiccation. Considering that the continuous spring wheat in our study has been grown since 2004 and was lightly tilled once prior to planting each season, it is likely that this practice has allowed for higher build up of wireworms in the soil.

SUMMARY

Spring wheat on rotational phase had greater arthropod abundance, demonstrating that crop rotation does not necessarily apply to any crop in reducing the number of arthropods present.

The pea interseeded with hay barley plots under the chemical, grazing, and mechanical treatments were inconsistent in the total arthropod abundance from year to year. The alfalfa root weevil, however, was found to be least abundant in the grazed-managed plots which suggest that sheep grazing could have caused the population of alfalfa root weevil to decrease. It also highly suggested that future experiments should include a control treatment for the pea/hay barley.

Grazing by sheep was as effective as applying herbicides in reducing the numbers of arthropods in the summer fallow plots. However, before the practice of sheep grazing to manage arthropod abundance can be fully incorporated into future agricultural systems, it is highly suggested that we wait for more promising results from further studies.

As for the alfalfa, it was found that the arthropod abundance among the Cimarron SR, HayGrazer, and Shaw alfalfa cultivars did not differ. This could have been because all three cultivars were grown in plots adjacent to each other. To test whether the arthropod abundance was affected spatially, future experiments should include the same cultivars grown in isolation of each other.

Wireworms, mostly *A. mellillus* were found to be most abundant in the continuous spring wheat plots than the other plots. However, it is important to keep in mind that wireworms are polyphagous and their presence can vary in both time and space. Thus, future control strategies should be based on the results of continuous monitoring programs.

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