2021

Quantitative Assessment of Aphid Parasitoids and Predators in Central Oklahoma Wheat Fields during Five Growing Seasons

Norman C. Elliott

Kristopher L. Giles

Kristen A. Baum

Sarah Elzay

Quantitative Assessment of Aphid Parasitoids and Predators in Central Oklahoma Wheat Fields during Five Growing Seasons

Norman C. Elliott, Kristopher L. Giles[1], Kristen A. Baum[2], and Sarah D. Elzay[2]

USDA-ARS Plant Science Research Laboratory, 1301 N. Western Rd., Stillwater, OK 74075

Abstract. Winter wheat (*Triticum aestivum* L.) is the most widely grown crop in Oklahoma and typically is planted in autumn and harvested in June. Wheat in Oklahoma is often infested by insect pests, the most important of which are the cereal aphids – greenbug, *Schizaphis graminum* (Rondani), and bird cherry-oat aphid, *Rhopalosiphum padi* (L.). We sampled a total of 69 wheat fields in central Oklahoma during five wheat-growing seasons. The number of wheat fields sampled ranged from seven in the 2016-2017 growing season to 24 fields in the 2009-2010 growing season. We used a D-vac suction sampler to collect aphids and their natural enemies in wheat fields in early November and again in the middle of March. During the five wheat-growing seasons, adult *Lysiphlebus testaceipes* (Cresson) and *Aphelinus nigritus* (Howard) were the most consistent and abundant parasitoids, with *L. testaceipes* present in each of the five growing seasons. The mean number of adult *L. testaceipes* per D-vac sample ranged from 1.38 in 2018-2019 to 64.3 adults per sample in the 2008-2009 growing season. *Aphelinus nigritus* was present in four of the five growing seasons and ranged from 0.86 to 7.82 adults per sample among the four growing seasons. Among arthropod predators, larval coccinellids were found in each growing season and ranged from 2.23 to 15.38 individuals per sample. Spiders were present in the five growing seasons and ranged from 1.63 to 19.0 per sample. Several other predator taxa in samples included Chrysopidae, Hemerobiidae, Nabidae, and Syrphidae. Abundance of most species increased from November to March. Abundance of most natural enemy species (or taxa) was positively correlated to aphid abundance, suggesting natural enemies had an aggregative and/or reproductive numerical response to aphid populations.

Introduction

Winter wheat (*Triticum aestivum* L.) with more than 2 million ha planted annually is the most widely grown crop in Oklahoma (Epplin et al. 1998, USDA NASS 2019). Winter wheat in central Oklahoma typically is planted during September and October and harvested in June. Several aphid species (Hemiptera: Aphididae) infest wheat fields in central Oklahoma. The most common and important species are the

[1]Department of Entomology and Plant Pathology, Oklahoma State University, 127 Noble Research Center, Stillwater, OK 74078
[2]Department of Integrative Biology, Oklahoma State University, 501 Life Sciences West, Stillwater, OK 74078

greenbug, *Schizaphis graminum* (Rondani); bird cherry-oat aphid, *Rhopalosiphum padi* (L.); and English grain aphid, *Sitobion avenae* (F.). Management programs for aphids in wheat in Oklahoma are based on conservation of parasitoids and judicious use of insecticides (Giles et al. 2003, Royer et al. 2015). *Lysiphlebus testaceipes* (Cresson) is the dominant aphid parasitoid in wheat in central Oklahoma and elsewhere on the Southern Plains (Kring and Gilstrap 1983, Giles et al. 2003, Elliott et al. 2018). *Diaeretiella rapae* (McIntosh) also is regularly observed at low levels in winter wheat fields, while *Aphelinus nigritus* (Howard) is found during the fall and spring months, but its patterns of occurrence are little studied (Kring and Gilstrap 1983; Giles et al. 2003, 2021; Elliott et al. 2018, 2019). Several other arthropod predators of aphids including species of Carabidae (French and Elliott 1999), Araneae (Greenstone 2001), and Coccinellidae, Chrysopidae, and Hemerobiidae (Rice and Wilde 1988, Michels et al. 2001, Lee et al. 2005, Elliott et al. 2006) inhabit wheat fields on the Southern Plains.

The purpose of this study was to document abundance and variation in abundance of aphids and natural enemies of aphids in wheat fields in central Oklahoma. A D-vac suction sampler (Dietrick 1961) was used to sample aphids and their arthropod natural enemies. Samples were collected in autumn and spring during five wheat-growing seasons. A D-vac is an efficient sampling device for aphids (Hand 1986) and for some arthropod natural enemies (Elliott et al. 2006) in wheat.

Materials and Methods

Commercial wheat fields in central Oklahoma were sampled twice during each of five wheat-growing seasons. Samples were obtained from each field in November and again the following March. The number of fields sampled during a growing season varied from seven to 24 (Table 1).

Table 1. Number of and Dates in Autumn and Spring of Each of Five Growing Seasons when Wheat Fields in Central Oklahoma were Sampled for Aphids and Natural Enemies

Growing season	Number fields sampled	Sampling dates (autumn / spring)
2008 - 2009	22	6-7 November / 17-18 March
2009 - 2010	24	10-11 November / 16-17 March
2016 - 2017	7	9 November / 15 March
2017 - 2018	8	8 November / 14 March
2018 - 2019	8	7 November / 12 March

A backpack Model 24 D-Vac® (Rincon-Vitova Insectaries, Inc., Ventura, CA) suction sampler fitted with a standard 33-cm-diameter collecting unit, fine-mesh organdy collecting bag, and fiberglass collar was used to sample aphids and natural enemies in wheat fields. Twenty suction samples were collected along each of three parallel transects approximately 100 m long (60 placements per field for a total area sampled of 51,292 cm^2). Transects were approximately 25 m apart and perpendicular to the nearest field edge. Each transect started approximately 10 m from the field edge. Approximately every 5 m along each transect, the D-vac collecting unit was placed straight down over growing wheat plants to just above the soil surface until 20 such placements had been made. Each time the collecting unit was placed down it was held in position slightly above the soil surface for 5 seconds. After 20 placements, the sampling bag was removed from the D-vac and all arthropods collected were transferred to a labeled plastic bag. Bags were brought to the laboratory, put into a freezer, and processed at a later date. Aphids and natural enemies from the three subsamples from each field were counted. The number of aphids in samples was recorded, as were the numbers of several natural enemies known to prey on aphids. Some natural enemies were identified to species. For others, the numbers of individuals in broader taxonomic groups instead of numbers of each species were recorded.

Mean, standard error, and range were calculated for the number of each natural enemy per D-vac sample. The total number of each natural enemy for the three 20 placement sub-samples were combined before calculating descriptive statistics (Tables 2-4). Thus, sample size was the number of wheat fields sampled. PROC MEANS (SAS Institute 2004) was used to calculate means and other descriptive statistics. Pearson correlation coefficients for aphid abundance to natural enemy abundance were calculated separately for autumn and spring data each growing season by using PROC CORR. Tests of significance of correlation coefficients were made at the $\alpha = 0.05$ significance level.

Results and Discussion

During the five growing seasons, adult *L. testaceipes* and *A. nigritus* were the most consistent and abundant parasitoids in wheat fields, with *L. testaceipes* present and abundant during all five growing seasons and *A. nigritus* present in four seasons but less abundant (Table 2). Comparison of abundance in samples would be meaningful only if sampling efficiency for the two parasitoid species was similar, which had not been studied but was probable considering similarity in size and morphology of the two species. *Diaeretiella rapae* was present and scarce during only two of the five growing seasons, suggesting the species is an uncommon parasitoid of aphids in wheat fields. Although *L. testaceipes* was present each year in wheat fields, its abundance varied more than 40 times among growing seasons, from the greatest 64.3 individuals per 60-placement sample in 2008-2009, to only 1.375 per sample in the 2018-2019 growing season. Previous studies documented *A. nigritus* as a parasitoid of cereal aphids in wheat on the Southern Plains (Kring and Gilstrap 1983, Elliott et al. 2019, Giles et al. 2021). The three parasitoid species (*L. testaceipes*, *D. rapae*, and *A. nigritus*) in wheat fields in central Oklahoma in this study were similar to those previously observed in wheat and sorghum fields throughout the region. Kring and Gilstrap (1983) observed parasitism by the same three species in similar relative abundance in wheat in central Texas. Both *L. testaceipes* and *A. nigritus* were in wheat fields in autumn and spring (Table 3). *Lysiphlebus testaceipes* parasitizes aphids throughout the winter in central Oklahoma (Giles et al. 2003). *Aphelinus nigritus* is not reported to reproduce in wheat during winter in central Oklahoma, although parasitism of cereal aphids by *A. nigritus* does occur in early November and in March (Giles et al. 2021). Abundance of *L. testaceipes* was significantly correlated to aphid abundance in wheat in both autumn and spring (Table 4), as was abundance of *A. nigritus*. Significant correlations suggested coupling of population dynamics of the two parasitoid species with that of aphids. *Lysiphlebus testaceipes* exerts significant mortality on cereal aphids in wheat in Oklahoma during the growing season and can maintain aphid abundance below the economic injury level (Giles et al. 2003). Apart from its occurrence in wheat, little is known of population interaction of *A. nigritus* and cereal aphids in wheat. Data from this study suggested relatively strong coupling of *A. nigritus* and cereal aphid population dynamics in wheat, but additional study is required to determine such a relationship.

Table 2. Average Number of Aphids and Natural Enemies in D-vac Samples from 69 Central Oklahoma Wheat Fields Sampled During Five Growing Seasons. Averages were calculated from numbers of insects in two 60-placement D-Vac samples, one in November and one in March (total of 120 placements per field).

Growing season	2008-2009	2009-2010	2016-2017	2017-2018	2018-2019
Number of fields	22	24	7	8	8
	$\bar{x}$ (*SE*)	$\bar{x}$ (*SE*)	$\bar{x}$ (*SE*)	$\bar{x}$ (*SE*)	$\bar{x}$ (*SE*)
Predator adults					
H. convergens	0.000	0.000	0.429 (0.202)	0.000	0.000
C. septempunctata	0.000	0.000	0.143 (0.143)	0.000	0.000
C. maculata	0.045 (0.045)	0.083 (0.058)	0.000	0.000	0.000
Chrysopidae	4.863 (1.061)	1.708 (0.369)	4.857 (2.304)	2.625 (1.511)	0.500 (0.267)
Hemerobiidae	0.000	0.000	0.571 (0.297)	0.250 (0.250)	0.000
Predator larvae					
Coccinellidae	2.227 (0.792)	2.417 (0.662)	5.000 (3.867)	4.250 (2.169)	15.38 (15.38)
Chrysopidae	0.000	0.417 (0.208)	1.429 (0.869)	0.000	0.000
Hemerobiidae	0.136 (0.100)	0.208 (0.104)	0.000	0.000	0.000
Syrphidae	0.727 (0.367)	0.125 (0.069)	0.571 (0.202)	0.000	0.250 (0.164)
Parasitoid adults					
L. testaceipes	64.27 (17.96)	3.125 (0.879)	5.286 (2.818)	38.25 (20.45)	1.375 (0.754)
D. rapae	0.000	0.000	0.143 (0.143)	2.000 (1.239)	0.000
A. nigritus	7.818 (3.777)	1.125 (0.347)	0.857 (0.857)	1.875 (0.854)	0.000
Adults+immatures					
Aphids	945.4 (276.8)	364.0 (72.71)	100.6 (37.85)	1173 (450.3)	703.6 (530.3)
Araneae	7.091 (1.435)	11.42 (1.531)	19.00 (8.826)	1.625 (0.653)	8.750 (2.548)
Nabidae	0.273 (0.117)	0.875 (0.284)	1.714 (0.644)	0.000	0.125 (0.125)
Orius spp.	1.500 (1.079)	0.167 (0.078)	4.857 (2.781)	0.000	0.250 (0.250)

Table 3. Average Number of Aphids and Natural Enemies in D-vac Samples from 69 Central Oklahoma Wheat Fields Sampled During Five Growing Seasons. Averages were calculated for numbers of insects in 60-placement D-Vac samples in autumn and spring (60 placements per field).

Enemy / life stage	November $\bar{x}$ (*SE*)	March $\bar{x}$ (*SE*)
Predator adults		
H. convergens	0.000	0.043 (0.025)
C. septempunctata	0.000	0.014 (0.014)
C. maculata	0.015 (0.015)	0.028 (0.020)
Chrysopidae	0.580 (0.265)	2.420 (0.428)
Hemerobiidae	0.014 (0.014)	0.072 (0.038)
Predator larvae		
Coccinellidae	0.072 (0.072)	4.261 (1.824)
Chrysopidae	0.029 (0.020)	0.261 (0.107)
Hemerobiidae	0.000	0.116 (0.049)
Syrphidae	0.087 (0.040)	0.275 (0.122)
Parasitoid adults		
L. testaceipes	0.086 (0.034)	26.62 (6.960)
D. rapae	0.000	0.246 (0.156)
A. nigritus	0.014 (0.014)	3.174 (1.259)
Adults + immatures		
Aphids	39.68 (10.52)	616.2 (126.5)
Araneae	3.333 (1.028)	6.029 (0.732)
Nabidae	0.159 (0.079)	0.420 (0.119)
Orius spp.	0.580 (0.353)	0.478 (0.311)

Adults of three species of Coccinellidae (*Hippodamia convergens* Guerin-Meneville, *Coccinella septempunctata* (L.), and *Coleomegilla maculata* L.) were captured in D-vac samples during the study (Table 2). Few adult coccinellids were captured, probably because of inadequate capture efficiency of D-vac for adult Coccinellidae in wheat (Elliott et al. 2006) because adult coccinellids were frequently observed while sampling wheat fields (N. Elliott personal observation). Adult coccinellids were more abundant in spring than autumn (Table 3).

Coccinellid larvae were present in each of the five growing seasons (Table 2) and more abundant in spring than autumn (Table 3). Results indicated that adults of the three coccinellid species inhabit wheat fields during autumn and spring and though species was not determined for Coccinellidae larvae one or more species reproduce in wheat fields during autumn and spring. Abundance of adult coccinellids and aphids was uncorrelated but might have been because of inadequate sampling efficiency of D-vac for adult coccinellids (Elliott et al. 2006). Abundance of coccinellid larvae was significantly and positively correlated with aphid abundance in autumn and spring (Table 4). Capture efficiency was several times greater for coccinellid larvae than adults (Elliott et al. 2006), which might explain the discrepancy between adult and larval abundance. Aggregative and reproductive numerical response by adult Coccinellidae to aphid abundance is well documented in literature (see Obrycki and Kring 1998 and references therein). Consistent occurrence of immature coccinellids in D-vac samples from wheat fields suggested adults were in wheat fields more consistently and in greater abundance than numbers in D-vac samples indicated. Consistent occurrence of Coccinellidae in wheat, apparent numerical response to aphid abundance, and well documented high voracity on aphids suggested Coccinellidae adults and larvae contribute significantly to biological control of cereal aphids in wheat in central Oklahoma.

Table 4. Correlations of Numbers of Aphids to Natural Enemies in D-vac Samples from 69 Central Oklahoma Wheat Fields Sampled during November and March of Five Wheat-growing Seasons. An asterisk denotes significant correlation.

Aphid enemy	November	March
Predator adults		
H. convergens	-	-0.12
C. septempunctata	-	-0.07
C. maculata	-0.04	-0.04
Chrysopidae	0.38*	0.61*
Hemerobiidae	0.23	-0.09
Predator larvae		
Coccinellidae	0.24*	0.48*
Chrysopidae	0.31*	-0.06
Hemerobiidae	-	-0.08
Syrphidae	0.02	0.58*
Parasitoid adults		
L. testaceipes	0.54*	0.48*
D. rapae		0.06
A. nigritus	0.62*	0.51*
Adults + immatures		
Araneae	0.22	-0.13
Nabidae	0.25*	0.01
Orius spp.	0.03	-0.09

Adult Chrysopidae (primarily *Chrysoperla carnea* (Stephens)) were abundant in samples in each of five growing seasons, while adult Hemerobiidae were in samples in two seasons (Table 2). Relative abundance of adult Chrysopidae compared to other natural enemies in samples was probably partly caused by high efficiency of D-vac suction sampling for adult Chrysopidae (Elliott et al. 2006). However, the consistency with which adult Chrysopidae were captured combined with great abundance indicated they frequently are in wheat fields during the growing season. Capture efficiency for adult Hemerobiidae would be expected to be similar to that of Chrysopidae because, although they are smaller than Chrysopidae their morphology is similar. Few adult and immature Hemerobiidae in samples indicated they were not in significant numbers in central Oklahoma wheat fields from November through mid-March.

There was a significant but small (r = 0.31) correlation of Chrysopidae larval abundance to aphid abundance for early November but no correlation for mid-March (Table 4). In the western U.S., adult *C. carnea* undergo migratory flights to overwintering sites in wooded edges and wetlands in late summer and early autumn and do not migrate back to feeding and reproduction habitats such as agricultural fields until spring. There was evidence of reproduction by chrysopids and hemerobiids during the wheat-growing season, with abundance of immature chrysopids about 10 times greater in mid-March than early November and immature hemerobiids increasing from 0 to 0.116 individual per sample from November to mid-March (Table 3). Observations suggest that neither Chrysopidae nor Hemerobiidae are typically abundant predators of aphids in central Oklahoma wheat fields.

Araneae (spiders) ranging from 1.625 to 19.0 per 120-placements of the D-vac (Table 2) were among the most abundant predators in wheat fields in central Oklahoma and almost twice as abundant in samples in March as in November (Table 3). The most abundant spiders in wheat on the Great Plains were Linyphiidae, Lycosidae, and Thomisidae (Greenstone 2001). Although spiders can kill significant numbers of aphids in wheat (Nyffeler and Benz 1988, Nyffeler and Sunderland 2003, Birkhofer et al. 2008, Sherawat and Butt 2014), they do not have a numerical response to aphids (Freier et al. 2007). Our study supported previous studies that documented spiders were among the most abundant predators in wheat fields, but their abundance was not correlated to aphid abundance (Table 4). Although they did not have a numerical response to cereal aphids in wheat fields in central Oklahoma as evidenced by lack of correlation between spider and aphid abundance, they might play a significant role in controlling infestations of cereal aphids in wheat because of they are abundant predators.

Nabidae and *Orius* spp. were in wheat fields during four of the five growing seasons (Table 2). Nabidae were more abundant in March than November (Table 3). *Orius* sp. occurred at similar abundance during November and March. Abundance of these predators was weakly or not correlated to aphid abundance in November or March, providing little evidence for numerical response to variation in aphid abundance (Table 4). Species of Nabidae and *Orius* feed on a variety of small, soft-bodied arthropods in addition to aphids (Salas-Aguilar and Ehler 1977, Lattin 1989) and also include plant material in their diet (van den Bosch and Hagen 1966, Lattin 1989, Armer et al. 1998). Despite their broad diet and relatively low consumption of aphids (Tamaki and Weeks 1972, Alvarado et al. 1997), heteropteran predators are consistently present in wheat fields in autumn and spring and might play a role in biological control of cereal aphids. Their suppressing abundance of cereal aphids might be important early in the wheat-growing season because they are present in the crop when aphids colonize in autumn.

Recent research on cereal aphid biological control in Oklahoma wheat fields focused primarily on a single natural enemy species, *L. testaceipes*, and its ability to maintain infestations by greenbugs in wheat fields below the economic injury level (Giles et al. 2000, 2003; Jones et al. 2003). Many arthropod predators and parasitoids are in wheat fields in central Oklahoma, and as this study demonstrated, some, such as Araneae and Coccinellidae, occur consistently in fields in autumn and spring. During autumn and early spring, infestations by greenbugs are most likely to exceed economic injury levels in wheat fields (Royer et al. 2015). Therefore, predators and parasitoids abundant during this time might play a significant role in biological control of cereal aphids.

Effectiveness of natural enemies in suppressing pest insect population growth in temporary habitats such as wheat fields is influenced by factors inherent to the life history of the natural enemy species in the habitat, and in the template of other habitats required for continued survival (Ehler and Miller 1978, Wissinger 1997, Elliott et al. 2018, 2019). Amounts of aphid biological control in wheat agroecosystems in central Oklahoma probably are the combined result of mortality exerted by the complex of natural enemies inhabiting the crop such as observed in other agroecosystems (Frazer et al. 1981, Snyder and Ives 2003. Freier et al. 2007).

Interspecies interactions among species of natural enemies such as interference competition and intra-guild predation that have been demonstrated to be important in wheat agroecosystems (Lang 2003, Royer et al. 2008) are mostly unknown and not studied in central Oklahoma wheat fields. Despite many unknowns regarding interspecies interactions among natural enemies, it is likely the combined contributions of several natural enemy taxa determine amounts of cereal aphid biological control achieved in the central Oklahoma wheat agroecosystem.

Acknowledgment

This research was supported by a grant from the U.S. Department of Agriculture (NIFA: 2017-67019-25919). We thank Tim Johnson and Georges Backoulou for technical assistance with the project. Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture. USDA is an equal opportunity provider and employer.

References Cited

Alvarado, P., O. Balta, and O. Alomar. 1997. Efficiency of four Heteroptera as predators of *Aphis gossypii* and *Macrosiphum euphorbiae* (Hom.: Aphididae). Entomophaga 42: 215-226.

Armer, C. A., R. N. Wiedenmann, and D. R. Bush. 1998. Plant feeding site selection on soybean by the facultatively phytophagous predator *Orius insidiosus*. Entomol. Exp. Appl. 86:109-118.

Birkhofer, K., E. Gavish-Regev, K. Endlweber, Y. D. Lubin, K. Von Berg, D. H. Wise, and S. Scheu. 2008. Cursorial spiders retard initial aphid population growth at low densities in winter wheat. Bull. Entomol. Res. 98: 249.

Dietrick, E. J. 1961. An improved backpack motor fan for suction sampling of insect populations. J. Econ. Entomol. 54: 394-395.

Ehler, L. E., and J. C. Miller. 1978. Biological control in temporary agroecosystems. Entomophaga 3: 207-212.

Elliott, N. C., F. L. Tao, R. Fuentes-Granados, K. L. Giles, D. T. Elliott, M. H. Greenstone, K. A. Shufran, and T. A. Royer. 2006. D-vac sampling for predatory arthropods in winter wheat. Biological Control 38: 325-330.

Elliott, N. C., M. J. Brewer, and K. L. Giles. 2018. Landscape context affects aphid parasitism by *Lysiphlebus testaceipes* (Hymenoptera: Aphidiinae) in wheat fields. Environ. Entomol. 47: 803-811.

Elliott, N. C., K. L. Giles, M. J. Brewer, and C. N. Jessie. 2019. Early season parasitism of cereal aphids in wheat fields and field borders. Southwest. Entomol. 44: 11-19.

Epplin, F. M., R. R. True, and E. G. Krenzer, Jr. 1998. Practices used by Oklahoma wheat growers by region. *In* Henneberry [ed.], Oklahoma: Current Farm Economics. DASNR, Oklahoma State University, Stillwater.

Ferguson, K. I., and P. Stiling. 1996. Non-additive effects of multiple natural enemies on aphid populations. Oecologia 108: 375-379.

Frazer, B. D., N. Gilbert, V. Nealis, and D. A. Raworth. 1981. Control of aphid density by a complex of predators. Canadian Entomol. 113: 1035-1041.

Freier, B., H. Triltsch, M. Möwes, and E. Moll. 2007. The potential of predators in natural control of aphids in wheat: results of a ten-year field study in two German landscapes. BioControl 52: 775-788.

French, B. W., and N. C. Elliott. 1999. Spatial and temporal distribution of ground beetle (Coleoptera: Carabidae) assemblages in riparian strips and adjacent wheat fields. Environ. Entomol. 28: 597-607.

Giles, K. L., T. A. Royer, N. C. Elliott, and S. D. Kindler. 2000. Development and validation of a binomial sequential sampling plan for the greenbug (Homoptera: Aphididae) infesting winter wheat in the Southern Plains. J. Econ. Entomol. 93: 1522-1530.

Giles, K. L., D. B. Jones, T. A. Royer, N. C. Elliott, and S. D. Kindler. 2003. Development of a sampling plan in winter wheat that estimates cereal aphid parasitism levels and predicts population suppression. J. Econ. Entomol. 96: 975-982.

Giles, K. L., N. C. Elliott, H. E. Butler, K. A. Baum, and G. F. Backoulou. 2021. Increase in importance of *Aphelinus nigritus* (Howard) in winter crops in Oklahoma coincides with invasion of sugarcane aphid in sorghum in Oklahoma. Southwest. Entomol. (in press).

Greenstone, M. H. 2001. Spiders in wheat: first quantitative data for North America. BioControl 46: 439-454.

Hand, S. C. 1986. The capture efficiency of the Dietrick vacuum insect net for aphids on grasses and cereals. Ann. Appl. Biol. 108: 233-241.

Jones, D. B., K. L. Giles, R. C. Berberet, T. A. Royer, N. C. Elliott, and M. E. Payton. 2003. Functional responses of an introduced parasitoid and an indigenous parasitoid on greenbug at four temperatures. Environ. Entomol. 32: 425-432.

Kring, T. J., and F. E. Gilstrap. 1983. Within-field distribution of greenbug (Homoptera: Aphididae) and its parasitoids in Texas winter wheat. J. Econ. Entomol. 76: 57-62.

Lang, A. 2003. Intraguild interference and biocontrol effects of generalist predators in a winter wheat field. Oecologia 134: 144-153.

Lattin, J. D. 1989. Bionomics of Nabidae. Annu. Rev. Entomol. 34: 383-400.

Lee, J. H., N. C. Elliott, S. D. Kindler, B. W. French, C. B. Walker, and R. D. Eikenbary. 2005. Natural enemy impact on the Russian wheat aphid in southeastern Colorado. Environ. Entomol. 34: 115-123.

Michels, G. J., N. C. Elliott, R. A. Romero, D. A. Owings, and J. B. Bible. 2001. Impact of indigenous coccinellids on Russian wheat aphids and greenbugs (Homoptera: Aphididae) infesting winter wheat in the Texas Panhandle. Southwest. Entomol. 26: 97-114.

Nyffeler, M., and G. Benz. 1988. Feeding ecology and predatory importance of wolf spiders (*Pardosa* spp.) (Araneae, Lycosidae) in winter wheat fields. J. Appl. Entomol. 106: 123-134.

Nyffeler, M., and K. D. Sunderland. 2003. Composition, abundance and pest control potential of spider communities in agroecosystems: a comparison of European and US studies. Agric., Ecosyst. Environ. 95: 579-612.

Obrycki, J. J., and T. J. Kring. 1998. Predaceous Coccinellidae in biological control. Annu. Rev. Entomol. 43: 295-321.

Rice, M. E., and G. E. Wilde. 1988. Experimental evaluation of predators and parasitoids in suppressing greenbugs (Homoptera: Aphididae) in sorghum and wheat. Environ. Entomol. 17: 836-841.

Royer, T.A., K.L. Giles, M.M. Lebusa, and M.E. Payton. 2008. Preference and suitability of greenbug, *Schizaphis graminum* (Hemiptera: Aphididae) mummies parasitized by *Lysiphlebus testaceipes* (Hymenoptera: Aphidiidae) as food for *Coccinella septempunctata* and *Hippodamia convergens* (Coleoptera: Coccinellidae). Biological Control 47:82-88.

Royer, T. A., B. B. Pendleton, N. C. Elliott, and K. L. Giles. 2015. Greenbug (Hemiptera: Aphididae) biology, ecology, and management in wheat and sorghum. J. Integrated Pest Manage. 6: 19.

Salas-Aguilar, J., and L. E. Ehler. 1977. Feeding habits of *Orius tristicolor*. Ann. Entomol. Soc. Am. 70: 60-62.

SAS Institute. 2004. SAS/STAT User's Guide, Version 9.1. SAS Institute, Cary, NC.

Sherawat, S. M., and A. Butt. 2014. Role of hunting spiders in suppression of wheat aphid. Pakistan J. Zool, 46: 309-315.

Snyder, W. E., and A. R. Ives. 2003. Interactions between specialist and generalist natural enemies: parasitoids, predators, and pea aphid biocontrol. Ecology 84: 91-107.

Tamaki, G., and R. E. Weeks. 1972. Efficiency of three predators, *Geoeoris bullatus*, *Nabis americoferus*, and *Coccinella transversoguttata*, used alone or in combination against three insect prey species, *Myzus persicae*, *Ceramica picta*, and *Mamestra configurata*, in a greenhouse study. Environ. Entomol. 1: 258-263.

USDA NASS (National Agricultural Statistics Survey). 2019. http://www.nass.usda.gov/

van den Bosch, R., and K. S. Hagen. 1966. Predaceous and parasitic arthropods in California cotton fields. Calif. Univ. Agric. Exp. Sta. Bull. 820.

Wissinger, S. A. 1997. Cyclic colonization in predictably ephemeral habitats: a template for biological control in annual crop systems. Biol. Control 10: 4-15.