JOURNAL OF THE KANSAS ENTOMOLOGICAL SOCIETY
77(3), 2004, pp. 165–173

Cereal Aphid and Natural Enemy Populations in Cereal Production Systems in Eastern Washington

S. L. CLEMENT, L. R. ELBERSON, N. YOUSSEF,[1] F. L. YOUNG,[2] AND M. A. EVANS[3]
USDA-ARS, Plant Germplasm Introduction and Testing Research Unit,
59 Johnson Hall, Washington State University, Pullman, Washington 99164-6402

ABSTRACT: A 5 yr study in the semiarid wheat production region of eastern Washington documented the relative densities of pest aphids and their natural enemies in cereal production systems using on-farm replicated plots. The systems were reduced-tillage soft white winter wheat (SWW) (*Triticum aestivum* L.)—summer fallow rotation; no-till soft white spring wheat (SWS)—chemical fallow rotation; continuous no-till hard red spring wheat (HRS); and no-till HRS—no-till spring barley (SB) (*Hordeum vulgare* L.) rotation. The English grain aphid, *Sitobion avenae* (F.), was the dominant species, followed in abundance by the Russian wheat aphid, *Diuraphis noxia* (Mordvilko). The bird cherry-oat aphid, *Rhopalosiphum padi* (L.), and rose grass aphid, *Metopolophium dirhodum* (Walter), were infrequently encountered. Overall, aphid densities were low, with aphids rare or absent in SWW and SB plots. The data revealed no clear and consistent effects of cereal production systems on aphid densities, but it did reveal, based on analysis of data from continuous HRS plots, high among-year variability in *S. avenae* and *D. noxia* densities. Only in 1996 and only in continuous HRS was it necessary to chemically control damaging populations of *D. noxia*. English grain aphid densities never approached threshold levels. *S. avenae* parasitism averaged >16% in some spring wheat systems in 1998 and 2000, while only two mummified *D. noxia* were observed. Coccinellid beetle counts in all plots totaled 143 in 1998 and 163 in 2000, with 90.2% and 94.5% in the genus *Hippodamia*, respectively. The ladybird beetle *Coccinella septempunctata* L. comprised 9.8% (1998) and 5.5% (2000) of the populations. The results suggest that damaging aphid populations are unlikely to develop in winter wheat, but populations in spring cereals warrant monitoring because they fluctuate from year-to-year and can be damaging.

KEY WORDS: *Sitobion avenae*, *Diuraphis noxia*, *Rhopalosiphum padi*, wheat, barley, pest management, aphid parasitism, coccinellid beetles, cropping systems research

The economic viability of the predominant soft white winter wheat—summer fallow rotation production system in eastern Washington is challenged by wind and water erosion on fallow ground, by invasive annual grass weeds, and by diseases (Young *et al.*, 1996; Launchbaugh *et al.*, 2000). A shift from this production system to a continuous no-till spring cropping system would provide sufficient residue to cover and protect the soil surface from erosion and would reduce the severity of annual grass seeds and some diseases (Young *et al.*, 1996). In the U.S. Pacific Northwest (PNW), however, spring—planted cereals are at greater risk of aphid-induced injury than fall-seeded crops because they support higher aphid populations (Feng *et al.*, 1991; Pike *et al.*, 1991; Elberson and Johnson, 1995). The primary aphid species (Homoptera: Aphididae) of economic importance to PNW cereals are the Russian wheat aphid, *Diuraphis noxia* (Mordvilko), bird cherry-oat aphid, *Rhopalosiphum padi* (L.), English grain aphid, *Sitobion avenae* (F.), rose grass aphid, *Metopolophium dirhodum* (Walter), greenbug, *Schizaphis graminum*

[1] Tennessee State University, Institute for Agricultural and Environmental Research, Otis L. Floyd Nursery Research Center, McMinnville, Tennessee 37110.
[2] USDA-ARS, Land Management and Water Conservation Research Unit, Washington State University, Pullman, Washington 99164-6416.
[3] Department of Statistics, Washington State University, Pullman, Washington 99164-3144.

Accepted 14 January 2004; revised 3 February 2004

(Rondani), and corn leaf aphid, *Rhopalosiphum maidis* (Fitch) (Pike *et al.*, 1991; Schotzko and Bosque-Pérez, 2000).

A long-term project was initiated in 1995 to evaluate no-till spring cereal production systems in the semiarid (<30.5 cm of annual rain) production region of eastern Washington for economic viability and environmental soundness, compared to the region's traditional winter wheat—fallow system (Young *et al.*, 1996; Thorne *et al.*, 2003). This multidisciplinary project included weed scientists, agronomists, plant breeders, soil scientists, plant pathologists, economists, entomologists, and wheat producers. The entomology component included sampling of insects in the production systems. An earlier paper documented Hessian fly, *Mayetiola destructor* (Say) (Diptera: Cecidomyiidae), populations and damage levels in the production systems (Clement *et al.*, 2003). In this paper, we quantify aphid pest populations and document the relative abundance of hymenopterous parasitoids and ladybird beetle predators in the large on-farm research plots. The implications of our findings for aphid pest management in the semiarid wheat production region of eastern Washington are briefly discussed.

Materials and Methods

This study spanned five growing seasons between 1995 and 2000 and was conducted on farm-scale plots in Adams County near Ralston, Washington (46°54′N, 118°24′W), where annual rainfall averages 26 cm. The soil type is a Ritzville silt loam (30.4% sand, 62% silt, 7.6% clay) and the soil pH and organic matter averaged 5.5 and 1.9%, respectively, at the onset of the study (Thorne *et al.*, 2003).

Two experimental areas (West and East plots) were established in 1995, each with four plots (replications) per cereal production system in a randomized complete block design. A cereal production system was randomly assigned to plots in each block in 1995 and remained in the same location for the duration of the study. West and East plots were within 460 m of each other and separated by a gravel road. The four systems were chronologically offset between the West and East plots so that each part of a two-year rotational cycle would be harvested each year. The two plot areas encompassed 8.1 ha.

The four cereal production systems were: (i) reduced-tillage soft white winter wheat (SWW) ('Lewjain' [1995–1998], 'Rely' [1998–2000])—summer fallow rotation (system 1 with West [1W] and East plots [1E]); (ii) no-till soft white spring wheat (SWS) ('Alpowa')—chemical fallow rotation (system 2W and 2E); (iii) continuous no-till hard red spring wheat (HRS) ('Butte 86' [1996–1998], 'Scarlet' [1999–2000]) (system 3W and 3E); and (iv) no-till HRS ('Butte 86' [1996–1998], 'Scarlet' [1999–2000])—no-till spring barley (SB) ('Baronesse') rotation (system 4W and 4E) (Table 1). None of these wheat and barley cultivars are resistant or tolerant to cereal aphids, although Clement *et al.* (2003) reported that Baronesse spring barley is resistant to Hessian fly (biotype GP).

In fall 1995 and spring 1996, East plots were started in standing stubble from the 1994–1995 SWW crop while West plots were started in summer fallow (Table 1). The plots (each 9.1 m wide and 152 m long) were separated by 3.1 m alleys, which were bare ground (2000) or planted to wheat in late May (1996–1999) to help prevent soil loss by wind erosion. Wheat and weeds in alleys were killed with herbicides and cultivation in August and September to remove potential over-wintering sites for insects. Fungicide seed treatments were used for pathogen suppression. All field operations were conducted with farm-size equipment. Complete agronomic information (soil fertility, planting dates, seeding rates, fertilizers, equipment and tillage operations, plant density data, fungicide

Table 1. Experimental production systems of soft white winter wheat (SWW), soft white spring wheat (SWS), hard red spring wheat (HRS), and spring barley (SB).

	Crop sequence†				
Production system*	1995–1996	1996–1997	1997–1998	1998–1999	1999–2000
1 W	SWW	Reduced-till fallow	SWW	Reduced-till fallow	SWW
1 E	Reduced-till fallow	SWW	Reduced-till fallow	SWW	Reduced-till fallow
2 W	SWS	Chemical fallow	SWS	Chemical fallow	SWS
2 E	Chemical fallow	SWS	Chemical fallow	SWS	Chemical fallow
3 W	HRS	HRS	HRS	HRS	HRS
3 E	HRS	HRS	HRS	HRS	HRS
4 W	HRS	SB	HRS	SB	HRS
4 E	SB	HRS	SB	HRS	SB

* System 1 (West and East plots) was reduced-tillage summer fallow and systems 2, 3, and 4 (West and East plots) were no-tillage. In 1995 and 1996, west plots were started in summer fallow and East plots were started in standing SWW stubble from the previous year's crop.

† SWW ('Lewjain' 1997–1998, 'Rely' 1998–2000); SWS ('Alpowa'); HRS ('Butte 86' 1997–1998, 'Scarlet' 1998–2000); SB ('Baronesse').

seed treatments and herbicide inputs) for each experimental production system was previously published (Thorne *et al*., 1998; Launchbaugh *et al*., 2000, 2001).

Aphid sampling: An in situ field count method was used to generate relative estimates of aphid populations (Elberson and Johnson, 1995), which involved fixed-time (2 min/0.4 m^2 sample unit) and whole-tiller visual counts and identifications of aphids. A strip 3.1 m wide along one side of each plot (9.1 m wide and 152 m long) was designated for pest insect sampling ('sampling strip'), with the rest of the plot reserved for crop harvest. At each census, we counted and identified all aphids on 10 randomly selected tillers (one tiller/plant) from each of 10 sample units (0.4 m^2 quadrats) per plot (100 tillers/plot). Quadrats were spaced 12–14 m apart in the 'sampling strip' of each plot and new ones were established on each census to avoid previously sampled tillers. Plant growth stage was recorded (Tottman *et al*., 1979) on each sampling date.

It was necessary to unroll leaves and sheaths to count *D. noxia* because they are most often found in rolled leaves and leaf sheaths (Pike *et al*., 1991; Elberson and Johnson, 1995). Also, the presence of external symptoms of *D. noxia*-induced damage (chlorosis; yellow, white, or purple streaking) (Clement *et al*., 1993) for each sampled tiller was recorded. During this 5 yr study, two investigators (S.L.C. and L.R.E.) collected the aphid data with one (S.L.C.) doing approximately 75% of the visual counts, identifications, and damage estimates.

Sampling began at the tillering stage of plant development. There were four aphid censuses in 1996 (1 and 30 May, 13 June, 2 July [all systems]); five in 1997 (6 and 19 May, 10 and 26 June, 10 July [all systems]); seven in 1998 (8 April [system 1], 4 and 18 May, 1 and 22 June [all systems], 6 July [systems 2,3, and 4], 29 October [system 1]); three in 1999 (1 and 30 June [all systems], 16 November [system 1]); and four in 2000 (9 March [system 1], 15 June [all systems], 27 June and 7 July [systems 2,3, and 4]). Mid- and late May 1999 and 2000 censuses were not scheduled after we failed to detect aphids during early May censuses of production systems 2, 3, and 4. Aphids were counted on a total of 400, 2000, and 2400 tillers on each day that system 1, systems 2–4, and all system plots were censused, respectively.

Aphid populations in plots that approached or exceeded economic thresholds were controlled with an insecticide application. Chemical control decisions were made on the basis of published economic thresholds for Russian wheat aphid (Halbert *et al.*, 1990; Fisher *et al.*, 1998), English grain aphid (Johnson and Bishop, 1987), and other cereal aphid species (Boeve and Weiss, 1997; Fisher *et al.*, 1998).

Natural enemy sampling: The relative abundance of hymenopterous parasitoids was determined by counting all mummified aphids on each sampled tiller. Parasitized aphids were identified but adult parasitoids were not reared from aphid mummies for identification. Mummified aphids were counted on all of the aforementioned 1996–2000 sampling dates, except on 16 November 1999.

Fixed-time (5 min) visual searches of all plants in a 1 by 10 m sampling area in the center of each plot were used to count and identify coccinellid beetles in 1998, 1999, and 2000 (all sampling dates, as listed above, except 29 October 1998 and 16 November 1999). Counts generated with this method represent relative densities because coccinellids at the base of wheat plants are difficult to observe and thus count (Chen and Hopper, 1997). Whole-plant visual counts were previously used to estimate the relative abundance of coccinellids in field crops (Bosque-Pérez *et al.*, 2002; Michels and Behle, 1992; Wright and DeVries, 2000). On each census date, ladybird beetles were counted before aphid counts were started in bordering 'sampling strips.' One investigator (N.Y.) did all of the lady beetle counts and identifications.

Data analysis: ANOVA procedures (SAS, 1999) were used to analyze aphid count data (peak numbers of each species per year) from the production systems (3W and 3E [continuous HRS]) that appeared every year in both experimental areas (Table 1). Mean numbers of aphids per plot (100 tillers) were subjected to ANOVA rather than mean numbers per tiller because aphid densities were low (see Results). Since each production system was analyzed separately, the analysis was based on a completely randomized design (location) with repeated measures (years). However, because these data did not meet parametric ANOVA assumptions of normality and homoscedasticity, non-parametric repeated measures ANOVA (Zar, 1996) was used to test for the effects of year, location (West plots vs. East plots), and the associated interaction on the density of each aphid species at $P = 0.05$. Data sets from other production systems also were characterized by wide-ranging count data, with 'zero counts' dominating most sets. Rather than subjecting these data to ANOVA analyses, we simply computed mean densities to allow assessment and comparison of relative aphid densities across all production systems and years.

To compare our aphid counts with economic thresholds and population levels from other PNW studies, we calculated mean numbers of *D. noxia* and *S. avenae* per tiller from 100 tillers per plot and then calculated an overall mean from the four replications (plot) of each production system.

Percentages of parasitized *S. avenae* were calculated using the total number of mummified aphids in all plots of each production system and the total number of aphids counted. These calculations were made for census dates yielding mummified aphids in data sets. Total ladybird beetle counts across all census dates were used to compute mean densities for each production system. Means for production systems with overlapping confidence intervals (95%) were assumed to be similar (Steel and Torrie, 1960).

Table 2. Seasonal occurrence of Russian wheat aphid, *Diuraphis noxia*, and English grain aphid, *Sitobion avenae*, in plots of soft white winter wheat (SWW), soft white spring wheat (SWS), hard red spring wheat (HRS), and spring barley (SB), 1996.

		Mean no. aphids per plot†							
		D. noxia				*S. avenae*			
Production system*	Crop	1 May	30 May	13 June	2 July	1 May	30 May	13 June	2 July
1 W	SWW	0	0	0	0	0.75	2.25	1.0	6.75
2 W	SWS	0	1.75	8.75	0.25	0	2.25	12.0	41.0
3 W	HRS	0	4.0	17.0	0.25	0.25	1.25	5.75	17.0
3 E	HRS	0	1.5	9.5	0.25	0	0.75	0.75	17.25
4 W	HRS	0	4.5	19.25	0	0.25	2.0	5.75	13.5
4 E	SB	0	0.75	0.25	0	0.5	0.75	0	5.0

* See Table 1 for system descriptions and crop sequences.
† Mean of 4 plots, 100 tillers/plot.

Results and Discussion

Aphids: The most abundant species was *S. avenae*, followed by *D. noxia*. Although there were no clear and consistent effects of the production systems on *S. avenae* and *D. noxia* population levels (Tables 2 and 3), their densities, based on mean values from continuous HRS plots, fluctuated significantly ($P < 0.0001$) from year-to-year. *Sitobion avenae* numbers were highest in 1996, 1997, and 2000. The highest densities of *D. noxia* were observed in 1996 and 2000, whereas the aphid was rare or absent at the research site in 1997, 1998, and 1999 (Tables 2 and 3). These general patterns corroborate Elberson and Johnson's (1995) report of high among-year variability in cereal aphid densities in wheat and barley fields in northern Idaho. The effects of other interactions (location, location $\times$ year) on *S. avenae* and *D. noxia* densities in continuous HRS plots were not significant ($P > 0.05$). Small numbers of *R. padi* (18 aphids), *M. dirhodum* (3), and unidentified aphids (10) were counted during this 5 yr study.

No aphids were observed during October 1998 and November 1999 censuses of SWW plots (seedling growth to tillering). The spring and summer occurrence patterns of *S. avenae* and *D. noxia* at the study site are reflected by the 1996 data (Table 2), and are in broad agreement with the seasonal patterns reported by Elberson and Johnson (1995) and Schotzko and Bosque-Pérez (2000) for these aphids on spring-planted cereals in northern Idaho. Each year of this study, peak densities of *D. noxia* were recorded in spring cereals between 1 and 27 June when plants were in the boot to early dough stages, whereas the highest *S. avenae* infestations were recorded between 22 June and 10 July when plants were in the inflorescence to hard dough stages (Tables 2 and 3). Monitoring pre-inflorescence spring cereals for *D. noxia* is important because persistent infestations of young plants can cause significant crop damage (Pike *et al.*, 1991; Legg and Archer, 1998). Monitoring plants for *S. avenae* during and after inflorescence is important because these later growth stages are most susceptible to damage by this aphid (Johnston and Bishop, 1987).

Mean numbers of *D. noxia* per tiller never exceeded 0.2 aphids for any production system. By comparison, Elberson and Johnson (1995) reported higher densities of *D. noxia* during 1989 to 1992 surveys of spring barley (0.13–16.17 aphids per tiller) and spring wheat fields (up to 21 aphids per tiller) in northern Idaho. Likewise, higher densities of this aphid were recorded in susceptible spring wheat in northern Idaho in 1997 (up to

Table 3. Peak densities of Russian wheat aphid, *Diuraphis noxia*, and English grain aphid, *Sitobion avenae*, in plots of soft white winter wheat (SWW), soft white spring wheat (SWS), hard red spring wheat (HRS), and spring barley (SB), 1997–2000.

		Mean no. aphids per plot†							
		D. noxia				*S. avenae*			
		1997	1998	1999	2000	1997	1998	1999	2000
Production system*	Crop	10 June	1 June		27 June	10 July	22 June	30 June	27 June
1 W, 1 E	SWW	—‡	—	—	—	29.25	0.25	—	—
2 W, 2 E	SWS	1.25	2.0	—	13.5	40.0	7.5	9.0	40.75
3 W	HRS	0.75	4.5	—	2.25	14.25	2.0	4.25	45.25
3 E	HRS	—	2.5	—	3.0	23.0	2.25	6.5	20.0
4 W, 4 E	HRS	—	3.25	—	15.0	30.0	2.0	5.5	50.5
4 W, 4 E	SB	—	—	—	2.75§	6.25	—	0.75	—

* See Table 1 for system descriptions and crop sequences. 2W, 4W (1998, 2000) and 2E, 4E (1997, 1999).
† Mean of 4 plots, 100 tillers/plot.
‡ No aphids observed.
§ Peak density on 15 June.

5.2 per tiller) and 1998 (up to 9.3 per tiller) (Bosque-Pérez *et al.*, 2002). Our results, together with those of Bosque-Pérez *et al.* (2002), may reflect *D. noxia* population declines in the PNW since its discovery in this region in 1987 and 1988 (Pike *et al.*, 1991). Indeed, Morrison *et al.* (1991) reported that economic losses caused by Russian wheat aphid had dropped in the U.S. after 1988, and Elberson and Johnson (1995) observed a dramatic drop in densities in the early 1990's in northern Idaho.

Only in 1996 did *D. noxia* infestations approach or reach a pre-determined treatment threshold level of 10% infested plants for pre-flowering spring cereals (Halbert *et al.*, 1990; Fisher *et al.*, 1998). We observed external symptoms of *D. noxia*—induced stress and recorded means of 8.25% and 10.5% infested plants (first awns, head emergence) for systems 3W and 4W (HRS), respectively, on 13 June 1996. This crop was sprayed with chlorpyrifos (Lorsban; DowElanco, Indianapolis, Indiana) at 0.56 kg (active ingredient) per ha on 14 June. System 3E and 2W plots averaged 5.25% and 5.5% infested plants, respectively, and were not sprayed. After 1996, *D. noxia*–infested plant levels averaged <1.25% for all production systems.

Economic thresholds for *S. avenae* vary considerably, ranging from 2 to 10 aphids per tiller for irrigated spring wheat in southern Idaho and 9 to 35 aphids per tiller for small grains in the Great Plains, with all values dependent upon plant growth stage (Johnson and Bishop, 1987; Boeve and Weiss, 1997). In this study, *S. avenae* densities never approached any of these threshold levels. Densities were highest in 1996, 1997, and 2000 (Tables 2 and 3) when the highest means were 0.41 (system 2W), 0.40 (system 2E), and 0.51 (system 4W) aphids per tiller, respectively.

Natural enemies: Except for two mummified *D. noxia*, all parasitized aphids were *S. avenae* and were counted on six censuses in the SWS and HRS production systems (Table 4). An assessment of the impact of hymenopterous parasitoids on *S. avenae* densities is difficult because of wide ranging parasitism levels (means from 0 to 33.3%) across census dates and spring wheat production systems. The highest levels of parasitism were observed in SWS and some HRS systems in 1998 and 2000 (up to 33.3%), although some of these levels were associated with low *S. avenae* densities (<19 aphids per production system)

Table 4. Percentage parasitism of *Sitobion avenae* on soft white spring wheat (SWS) and hard red spring wheat (HRS), 1996–1998 and 2000*.

		% Parasitism (total aphids)‡					
		1996	1997	1998		2000	
Production system†	Crop	2 July	10 July	22 June	6 July	27 June	7 July
2 W, 2 E	SWS	4.3 (163)	5.0 (160)	16.7 (30)	16.7 (18)	1.8 (163)	27.3 (33)
3 W	HRS	2.9 (68)	3.5 (57)	0.0 (8)	0.0 (1)	0.6 (181)	17.6 (51)
3 E	HRS	2.9 (69)	1.1 (92)	0.0 (9)	25.0 (12)	0.0 (80)	8.3 (36)
4 W, 4 E	HRS	3.7 (54)	4.2 (120)	0.0 (8)	33.3 (9)	0.0 (202)	20.4 (49)

* No mummified aphids were observed in 1999 SWW and SB plots, and on other SWS and HRS census dates.
† See Table 1 for system descriptions and crop sequences. 2W, 4W (1996, 1998, 2000) and 2E, 4E (1997).
‡ Percentages based on total number of *S. avenae* counted in the four plots of each production system.

(Table 4). We expected higher recoveries of mummified *D. noxia* because exotic hymenopterous parasitoids had been mass released from 1988 to 1992 in Washington for the biological control of this aphid (Tanigoshi *et al.*, 1995; Pike *et al.*, 1997). One could attribute our low recovery of parasitized *D. noxia* to low plant diversity (winter and spring cereals, fallow cropland) in areas surrounding the research plots. High plant diversification in wheat production areas has been associated with increased parasitoid abundance for biocontrol of *D. noxia* (Ahern and Brewer, 2002).

Coccinellid beetles were detected in 1998 and 2000, but not in 1999 when very few aphids were observed (Table 3). Of the 143 and 163 coccinellid beetles observed in 1998 (majority [97.2%] counted in June and July) and 2000 (100% counted in June and July), respectively, 90.2% and 94.5% were in the genus *Hippodamia*. Although the identity of these beetles was not always established, most were probably the native species *H. convergens* Guerin. The other coccinellid encountered was the introduced European species *Coccinella septempunctata* L., which comprised 9.8% (1998) and 5.5% (2000) of the populations. Likewise, the density of *C. septempunctata* was low compared to *H. convergens* in spring wheats in northern Idaho in 1997 and 1998 (Bosque-Pérez *et al.*, 2002).

In 1998 and 2000, coccinellid beetle densities were very low in SWW (6 beetles counted in both years) and SB (8 beetles), precluding calculation of meaningful 95% confidence intervals around mean values. Based on overlap of 95% confidence intervals, mean coccinellid densities in SWS (14.25 in 1998, 12.75 in 2000) and HRS system plots (means from 5.5 to 11.25, 1998 and 2000) were similar.

Pest management considerations: The results of this 5 yr study have implications for the sampling and management of aphids as occasional pests of cereals in the semiarid wheat production region of eastern Washington. First, censuses of SWW plots revealed a low probability for economic populations developing in commercial winter wheat, whereas sampling of SWS and HRS plots detected year to year fluctuations in *D. noxia* and *S. avenae* densities, thus suggesting the need for monitoring aphid populations in spring cereals. Monitoring of aphid populations is required to determine the need for chemical control measures in spring wheat. Our results bracket June and July sampling periods and SWS and HRS growth stages for pest aphid monitoring. Second, surveys of wheat fields should document the relative densities of ladybird beetles to estimate their value as biological control agents of *S. avenae* and other pest aphids. Finally, the collective results of aphid (this study) and Hessian fly sampling (Clement *et al.*, 2003) in the production system plots suggest there is a greater risk for high Hessian fly populations developing in the semiarid wheat production area of eastern Washington, especially over time in no-till spring wheat fields.

Acknowledgments

We thank V. Nebling, M. Ney, T. Davis, C. Doggett, and K. Williams for assistance in recording field data, and Larry McGrew for the establishment and maintenance of the research site. We are indebted to Curtis Hennings for providing commercial farmland for this long-term study. We also thank Nilsa Bosque-Pérez and John Burns for reviewing our manuscript. Funding for this research was provided by grants (Washington State Department of Ecology, Solutions to Economic and Environmental Problems [STEEP II]; Columbia Plateau PM^{10} Wind Erosion/Air Quality Project) awarded to the overall project leader (F.L. Young). Mention of a trademark or proprietary product does not constitute a guarantee or warranty by the USDA and does not imply its approval over other suitable products.

Literature Cited

Ahern, R. G., and M. J. Brewer. 2002. Effect of different wheat production systems on the presence of two parasitoids (Hymenoptera: Aphelinidae; Braconidae) of the Russian wheat aphid in the North American Great Plains. Agriculture, Ecosystems and Environment 92:201–210.

Boeve, P. J., and M. Weiss. 1997. Binomial sequential sampling plans for cereal aphids (Homoptera: Aphididae) in spring wheat. Journal of Economic Entomology 90:967–975.

Bosque-Pérez, N. A., J. B. Johnson, D. J. Schotzko, and L. Unger. 2002. Species diversity, abundance, and phenology of aphid natural enemies on spring wheats resistant and susceptible to Russian wheat aphid. BioControl 47:667–684.

Chen, K., and K. R. Hopper. 1997. *Diuraphis noxia* (Homoptera: Aphididae) population dynamics and impact of natural enemies in the Montpellier region of southern France. Environmental Entomology 26: 866–875.

Clement, S. L., D. G. Lester, and D. M. Stout. 1993. Colonization of grass germplasm nurseries by *Diuraphis noxia* (Mordvilko) (Homoptera: Aphididae). Journal of the Kansas Entomological Society 66:254–256.

Clement, S. L., L. R. Elberson, F. L. Young, J. R. Alldredge, R. H. Ratcliffe, and C. Hennings. 2003. Variable Hessian fly (Diptera: Cecidomyiidae) populations in cereal production systems in Eastern Washington. Journal of the Kansas Entomological Society 76:567–577.

Elberson, L. R., and J. B. Johnson. 1995. Population trends and comparisons of sampling methods for *Diuraphis noxia* and other cereal aphids (Homoptera: Aphididae) in northern Idaho. Environmental Entomology 24:538–549.

Feng, M. G., J. B. Johnson, and S. E. Halbert. 1991. Natural control of cereal aphids (Homoptera: Aphididae) by entomopathogenic fungi (Zygomycetes: Entomophthorales) and parasitoids (Hymentoptera: Braconidae and Encyrtidae) on irrigated spring wheat in southwestern Idaho. Environmental Entomology 20:1699–1710.

Fisher, G., J. DeAngelis, C. Baird, R. Stoltz, L. Sandvol, A. Antonelli, and E. Beers. 1998. Pacific Northwest Insect Control Handbook. Oregon State University, Corvallis, Oregon.

Halbert, S. E., L. E. Sandvol, R. L. Stoltz, and H. W. Homan. 1990. Russian Wheat Aphid. Agricultural Experiment Station, Current Information Series no. 817. University of Idaho, Moscow, Idaho.

Johnston, R. L., and G. W. Bishop. 1987. Economic injury levels and economic thresholds for cereal aphids (Homoptera: Aphididae) on spring-planted wheat. Journal of Economic Entomology 80:478–482.

Launchbaugh, K., L. McGrew, and F. Young. 2000. Integrated Spring Cropping Systems for the Semiarid Wheat-fallow Region 2000. Department of Crop and Soil Science, Technical Report 00-4. Washington State University, Pullman, Washington.

Launchbaugh, K., L. McGrew, and F. Young. 2001. Integrated Spring Cropping Systems for the Semiarid Wheat-fallow Region 2001. Department of Crop and Soil Science, Technical Report 01-2. Washington State University, Pullman, Washington.

Legg, D. E., and T. L. Archer. 1998. Sampling methods, economic injury levels, and economic thresholds for the Russian wheat aphid (Homoptera: Aphididae). *In* S. S. Quisenberry and F. B. Peairs (eds.). Response Model for an Introduced Pest—The Russian Wheat Aphid, pp. 313–336. Proceedings Thomas Say Publications in Entomology, Entomological Society of America, Lanham, Maryland.

Micheles, G. J., Jr., and R. W. Behle. 1992. Evaluation of sampling methods for lady beetles (Coleoptera: Coccinellidae) in grain sorghum. Journal of Economic Entomology 85:2251–2257.

Morrison, P., L. Brooks, G. Hein, G. Johnson, W. Massey, D. McBride, F. Peairs, J. T. Schultz, and D. Legg. 1991. Economic Impact of the Russian Wheat Aphid in the Western United States: 1989–1990. Great Plains Agriculture Council Publication 139.

Pike, K. S., D. Allison, L. K. Tanigoshi, R. F. Harwood, S. L. Clement, S. E. Halbert, C. M. Smith, J. B. Johnson, G. L. Reed, and P. K. Zwer. 1991. Russian Wheat Aphid Biology, Damage, and Management. Washington, Oregon, Idaho: Pacific Northwest Extension Publication. Number 371.

Pike, K. S., P. Starý, T. Miller, D. Allison, L. Boydston, G. Graf, and R. Gillespie. 1997. Small-grain aphid parasitoids (Hymenoptera: Aphelinidae and Aphidiidae) of Washington: distribution, relative abundance, seasonal occurrence, and key to known North American species. Environmental Entomology 26:1299–1311.

SAS Institute. 1999. SAS/STAT User's Guide, Version 8. SAS Institute, Cary, North Carolina.

Schotzko, D. J., and N. A. Bosque-Pérez. 2000. Seasonal dynamics of cereal aphids on Russian wheat aphid (Homoptera: Aphididae) susceptible and resistant wheats. Journal of Economic Entomology 93:975–981.

Steel, R. G. D., and J. H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill, New York, New York.

Tanigoshi, L. K., K. S. Pike, R. H. Miller, T. D. Miller, and D. Allison. 1995. Search for, and release of, parasitoids for the biological control of Russian wheat aphid in Washington State (USA). Agriculture, Ecosystems and Environment 52:25–30.

Thorne, M. A., and F. L. Young. 1998. Integrated Spring Cropping Systems for the Semiarid Wheat-fallow Region 1998. Department of Crop and Soil Science, Technical Report 98-1. Washington State University, Pullman, Washington.

Thorne, M. A., F. L. Young, W. L. Pan, R. L. Alldredge, and B. Bafus. 2003. No-till spring cereal cropping systems reduce wind erosion susceptibility in the wheat/fallow region of the Pacific Northwest. Journal of Soil and Water Conservation 58:250–257.

Tottman, D. R., R. J. Makepeace, and H. Broad. 1979. An explanation of the decimal code of the growth stages of cereals, with illustrations. Annals of Applied Biology 93:221–234.

Wright, R. J., and T. A. DeVries. 2000. Species composition and relative abundance of Coccinellidae (Coleoptera) in south central Nebraska field crops. Journal of the Kansas Entomological Society 73: 103–111.

Young, F., A. Ogg, K. Kidwell, and B. Pan. 1996. Integrated crop production of spring wheat in dryland wheat. *In* R. Papendick and R. Veseth (eds.). Northwest Columbia Plateau, Wind Erosion Air Quality Project, pp. 28–32. College of Agriculture and Home Economics, Misc. Pub. No. MISC0184. Washington State University, Pullman, Washington.

Zar, J. H. 1996. Biostatistical Analysis. Prentice Hall, Upper Saddle River, New Jersey.