

Parasitism of the Wheat Stem Sawfly (Hymenoptera: Cephidae) by *Bracon cephi* and *B. lissogaster* (Hymenoptera: Braconidae) in Wheat Fields Bordering Tilled and Untilled Fallow in Montana

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ABSTRACT We evaluated wheat stem sawfly, *Cephus cinctus* Norton, parasitism, infestation, and sawfly-cut stems in wheat fields bordering intensely tilled (no visible stubble residue), minimally tilled (>75% stubble residue visible), and untilled (chemical fallow, herbicide fallow management) summer fallow fields in north-central and south-central Montana. No difference in sawfly parasitism or sawfly-cut stems was found between fields bordering minimally tilled and fields bordering untilled summer fallow. Sawfly parasitism in fields bordering untilled summer fallow was greater than in fields bordering intensely tilled summer fallow at six of the eight sites examined. Sawfly-cut stems were greater in the field bordering intensely tilled fallow at four sites, with no difference in sawfly-cut stems between the intensely tilled and untilled field at the other four sites. Although it has never been reported, we have observed that many sawfly stubs are completely buried. Therefore, we measured the depth of sawfly stubs in four untilled fields in Broadwater County, MT. Two-thirds of the stubs were completely buried (206 of 300) with an average depth of 6 mm. Intensive tillage, which results in soil-covered stubble, is not an effective sawfly control practice, because sawflies typically overwinter below ground and upon emergence must dig to reach the soil surface. However, *Bracon cephi* (Gahan) and *Bracon lissogaster* Muesebeck overwinter above ground in stems and might be unable to dig to the soil surface if buried. The elimination of intensive tillage in favor of chemical fallow should result in greater sawfly parasitism over time. Producers replacing minimal tillage with chemical fallow should see no effect on sawfly parasitism.

KEY WORDS Wheat stem sawfly, *Cephus cinctus*, *Bracon cephi*, *Bracon lissogaster*, tillage, chemical fallow

IN THE NORTHERN Great Plains, the wheat stem sawfly, *Cephus cinctus* Norton, is an economically important insect pest of wheat, *Triticum aestivum* L. (Weiss and Morrill 1992, Morrill et al. 2001). Sawfly-infested plants have reduced yields and usually lodge, reducing the amount of grain that can be harvested (Ainslie 1920, Platt and Farstad 1946, Holmes 1977). In Montana alone, annual losses caused by sawfly infestations have been estimated to exceed \$25 million (Montana State University Extension Service 1997).

Female sawflies deposit their eggs in the developing stems of wheat, and larvae feed and complete development within the stems. Mature larvae chew a notch around the inside perimeter of the stems near ground level and overwinter in the underground region of the stem below this notch. Stems usually break at this notch (called "sawfly-cutting"), leaving a "stub" that serves as an overwintering chamber (Ainslie 1920, Holmes 1954, Weiss and Morrill 1992). Sawflies are

difficult to control because eggs, larvae, and pupae are enclosed within host plants. Current management practices do not provide adequate levels of control (Morrill et al. 2001).

Bracon cephi (Gahan) and *Bracon lissogaster* Muesebeck are the only wheat stem sawfly parasitoids that commonly occur in wheat. Levels of parasitism vary greatly among fields (Morrill 1997, 1998). The life histories of these idiobiont ectoparasitoids are similar. *B. cephi* and *B. lissogaster* have two generations per year. Once a host has been located, females insert their ovipositor into the stem, paralyze the sawfly larva, and deposit one to four eggs (Nelson and Farstad 1953, Holmes et al. 1963). Larvae feed on the surface of the host and consume the sawfly larvae through minute lacerations made with the mandibles (Somsen and Luginbill 1956). Mature larvae spin a cylindrical cocoon that is attached lengthwise to the inside of the stem at each end by a disc-like plate. Larvae pupate in the spring, and adults emerge by chewing a circular hole in the stem wall (Nelson and Farstad 1953).

Alternate-year summer fallow-wheat production is a typifying feature of dryland farming in Montana (Willis et al. 1983, Troeh et al. 1999). This crop-fallow

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Table 1. Research site locations in Montana, year(s) sampled, tillage type, and wheat variety

Site	Year	County	Location	Tillage type	Variety
1	1998	Chouteau	47° 50' N, 111° 17' W	Minimum	'Rampart'
2	1998	Chouteau	47° 58' N, 111° 22' W	Minimum	'Rampart'
3	1998/1999	Cascade	47° 41' N, 111° 37' W	Minimum	'Rocky'
4	1998	Teton	47° 57' N, 111° 47' W	Minimum	'Vanguard'
5	1998	Toole	48° 16' N, 111° 49' W	Intensive	'Ernest'
6	1998	Stillwater	45° 45' N, 109° 07' W	Intensive	'Vanguard'
7	1999	Chouteau	47° 50' N, 111° 19' W	Intensive	'Rampart'
8	1999	Chouteau	48° 00' N, 111° 08' W	Intensive	'Vanguard'
9	2000	Teton	47° 49' N, 111° 59' W	Intensive	'Tiber'
10	2001	Cascade	47° 41' N, 111° 32' W	Intensive	'Vanguard'
11	2001	Pondera	48° 02' N, 111° 29' W	Intensive	'Rampart'
12	2001	Chouteau	48° 02' N, 111° 10' W	Intensive	'Rampart'

system consists of the current crop adjacent to idle fields in which the previous year's crop was located. Tillage and/or herbicides are commonly used to manage weeds on fallow land in Montana. Tillage, mechanical disturbance that results in inversion of the soil, uproots and buries seedlings and mature weeds (Troeh et al. 1999). Chemical fallow is an untilled summer fallow system in which weeds are controlled with herbicides, and the soil is left undisturbed (Blevins and Frye 1993). Sawflies and their parasitoids overwinter in postharvest wheat stubble. The effects of stubble management on sawfly populations have been extensively investigated (Criddle 1922, Callenbach and Hansmeier 1944, Farstad et al. 1945, Holmes and Farstad 1956, Weiss et al. 1987, Morrill et al. 1993, Goosey 1999); however, nothing has been reported about the effects of stubble management on levels of sawfly parasitism. The objectives of this study were to examine the effects of fallow management on populations of wheat stem sawfly and its associated parasitoids. Specifically, we wished to determine if we could discern differences at the field level for both trophic levels, and if we could detect any direct impact of weed management on the number of sawfly-cut stems, the criterion used by producers to gauge the severity of their sawfly infestations.

Materials and Methods

Field Selection. Two wheat fields, one bordering either intensely tilled or minimally tilled summer fallow and an adjacent field bordering untilled summer fallow, were compared at each of 12 sites in Montana during 1998–2001 (Table 1). Sites varied in the amount of annual rainfall, wheat varieties grown, application of soil amendments, and soil type. Insecticide use is uncommon in dryland wheat production in Montana. The sites selected covered a broad area of the agricultural landscape in the wheat producing area of Montana, with a distance of 310 km separating the sites furthest apart. The tilled and untilled field at each site was carefully chosen to match wheat variety and field size, but it was not possible to select similar sites throughout the entire study area. Tillage type was categorized by the amount of crop residue on the soil surface. Tilled summer fallow with >75% of the stubble remaining on the soil surface were designated as

“minimum tillage”, and summer fallow fields with no visible stubble were labeled “intensive tillage.” Sites were sampled with a sweep net (before the appearance of parasitoids) to ensure the presence of sawflies.

Stem Sampling. Plant samples were collected at each location to determine sawfly infestation and parasitism levels. Four samples were taken along the long axis of each field edge that bordered the adjacent fallow field. Mature plant stems were collected immediately before harvest by uprooting entire plants. Samples consisted of four replicates of all stems in a 30-cm length of a row located within 1–5 m of the field border. Field edges were sampled because sawfly oviposition occurs as soon as suitable hosts are encountered; therefore, infestations are concentrated in field borders (Hitchcock 1942, Morrill et al. 2000). Samples were taken from the same side of each field (i.e., from east edge) at each location because sawflies fly upwind to existing crops, often causing sawfly infestation and parasitism levels to vary between opposing field edges.

Stem Processing. Each stem was dissected lengthwise with an X-ACTO knife (Hunt Corp., Statesville, NC). Sawfly infestation was determined by the presence of characteristic frass resulting from the feeding of the sawfly larva within the stem. The cleanly cut, frass-plugged lower portions of stems were easily recognized as sawfly-cut stems. Sawfly parasitism levels were determined by the presence of parasitoid cocoons and the distinctive adult parasitoid emergence holes. Plants were held in the lab for 1 mo to allow completion of parasitoid development and cocoon construction before each stem was dissected.

Sawfly Stub Depth. The distance of the apex (point from which sawflies emerge) of sawfly stubs from the soil surface was measured in four untilled fields in Broadwater County, in October 2001. “Stub” depth was obtained by placing a meter stick level on the soil surface along a row, digging under the meter stick until a stub was located, and measuring the distance from the top of the stub to the bottom of the meter stick. The depth of 25 stubs in five randomly selected rows was obtained in each field. Two fields contained the current year's stubble (sawflies that will emerge the following spring), and two fields contained the previous year's stubble (sawflies that emerged 5 to 6 mo before measurement).

Table 2. Comparison of percent sawfly-infested stems (mean $\pm$ SEM), sawfly-cut stems, and sawfly parasitism in wheat fields bordering tilled and untilled summer fallow in Montana

Site	Bordering fallow field	Mean $\pm$ SEM no. stems/sample	% Sawfly-infested stems	<i>t</i> value	<i>P</i>	% Sawfly-cut stems	<i>t</i> value	<i>P</i>	% Sawfly Parasitism	<i>t</i> value	<i>P</i>
1	Minimally tilled	76 $\pm$ 7	87 $\pm$ 4	-0.49	0.67	9 $\pm$ 2	-0.77	0.51	55 $\pm$ 12	2.14	0.09
	Untilled	71 $\pm$ 9	92 $\pm$ 3			15 $\pm$ 3			41 $\pm$ 8		
2	Minimally tilled	125 $\pm$ 15	77 $\pm$ 3	-1.64	0.20	14 $\pm$ 2	0.03	0.97	48 $\pm$ 9	-1.22	0.16
	Untilled	136 $\pm$ 9	84 $\pm$ 8			14 $\pm$ 3			58 $\pm$ 6		
3 ^a	Minimally tilled	88 $\pm$ 11	44 $\pm$ 4	0.23	0.83	6 $\pm$ 2	-2.01	0.09	27 $\pm$ 9	0.79	0.44
	Untilled	96 $\pm$ 6	43 $\pm$ 8			12 $\pm$ 7			20 $\pm$ 7		
4	Minimally tilled	84 $\pm$ 16	39 $\pm$ 5**	-5.37	0.01	5 $\pm$ 1	-0.74	0.60	45 $\pm$ 12	-2.37	0.07
	Untilled	96 $\pm$ 12	53 $\pm$ 7			8 $\pm$ 3			69 $\pm$ 16		
3 ^b	Minimally tilled	96 $\pm$ 8	34 $\pm$ 6	2.39	0.11	10 $\pm$ 2	0.88	0.44	18 $\pm$ 7	0.44	0.29
	Untilled	101 $\pm$ 10	25 $\pm$ 8			9 $\pm$ 1			15 $\pm$ 3		
5	Intensely tilled	148 $\pm$ 21	38 $\pm$ 4**	24.65	<0.01	15 $\pm$ 2**	21.98	<0.01	7 $\pm$ 7**	-4.47	<0.01
	Untilled	159 $\pm$ 16	9 $\pm$ 2			0 $\pm$ 0			39 $\pm$ 12		
6	Intensely tilled	196 $\pm$ 17	11 $\pm$ 2	0.02	0.98	3 $\pm$ 2**	4.96	0.02	5 $\pm$ 3**	-16.62	<0.01
	Untilled	211 $\pm$ 15	11 $\pm$ 4			0 $\pm$ 0			81 $\pm$ 17		
7	Intensely tilled	144 $\pm$ 13	38 $\pm$ 12	1.33	0.17	11 $\pm$ 3**	8.12	0.01	20 $\pm$ 11	-1.18	0.17
	Untilled	130 $\pm$ 12	35 $\pm$ 9			4 $\pm$ 3			32 $\pm$ 16		
8	Intensely tilled	111 $\pm$ 7	52 $\pm$ 14	1.02	0.28	9 $\pm$ 2**	7.73	<0.01	56 $\pm$ 9**	-4.54	0.03
	Untilled	109 $\pm$ 12	42 $\pm$ 4			3 $\pm$ 1			74 $\pm$ 8		
9	Intensely tilled	166 $\pm$ 21	72 $\pm$ 8	-0.10	0.93	19 $\pm$ 4	0.87	0.54	31 $\pm$ 4**	-5.56	0.01
	Untilled	186 $\pm$ 13	84 $\pm$ 7			18 $\pm$ 4			59 $\pm$ 3		
10	Intensely tilled	121 $\pm$ 9	6 $\pm$ 2**	-8.56	<0.01	4 $\pm$ 2	-2.36	0.07	0 $\pm$ 0**	-7.57	0.01
	Untilled	115 $\pm$ 3	18 $\pm$ 4			8 $\pm$ 3			22 $\pm$ 3		
11	Intensely tilled	241 $\pm$ 9	41 $\pm$ 6	0.25	0.81	6 $\pm$ 3	-0.81	0.49	15 $\pm$ 8**	-3.28	0.02
	Untilled	211 $\pm$ 16	40 $\pm$ 9			8 $\pm$ 5			31 $\pm$ 6		
12	Intensely tilled	98 $\pm$ 11	28 $\pm$ 7	1.14	0.39	8 $\pm$ 2	0.06	0.97	29 $\pm$ 9	0.29	0.82
	Untilled	114 $\pm$ 24	25 $\pm$ 5			8 $\pm$ 4			27 $\pm$ 13		

For each comparison, df = 3; *t* and *P* values apply to comparison in preceding column.

** indicates significant difference at α = 0.05.

^a 1998.

^b 1999.

Statistical Analysis. The experimental design allowed for careful comparison between tilled and untilled summer fallow fields at each site. However, the great variation in agricultural practices and environmental conditions across sites precluded an analysis of variance (ANOVA) procedure by violating the underlying assumptions for this approach. Therefore, a paired *t*-test was conducted for each site, and general conclusions are drawn based on these repeated independent analyses. The *t*-test procedure of the SAS Statistical Package (PROC *t*-test, SAS Institute 1990) was used in a paired comparison by site, evaluating mean percentage of sawfly infestation, cut stems, and sawfly parasitism between fields that bordered tilled and untilled summer fallow. Percent data were transformed using the arcsine transformation.

Results and Discussion

Sawfly parasitism was statistically greater in the field that bordered untilled summer fallow than the field that bordered intensely tilled summer fallow at six of the eight sites, suggesting that intense tillage in which all stubble is buried could be detrimental to sawfly parasitoids (Table 2). Sawfly parasitoids overwinter above ground in stems and might be unable to dig to the soil surface if buried. Samples from fields bordering intensely tilled summer fallow contained notably fewer total parasitoids than fields bordering untilled summer fallow (177 and 415 total parasitoids in fields bordering intensely tilled and untilled summer fallow,

respectively). There was no difference in mean percentage of sawfly infestation between the field bordering intensely tilled fallow and untilled fallow at six of the eight sites (Table 2). However, intensive tillage that incorporates sawfly-infested stubble into the soil was recommended as a control tactic (Criddle 1922, Farstad et al. 1945). Recently, Goosey (1999) reported no difference in sawfly mortality between intensely tilled and untilled fields, which is consistent with our findings. Sawflies overwinter below ground in stubs that are often completely buried and following emergence must dig to reach the soil surface (Table 3). The ability of sawflies to escape from their soil-covered stubs upon emergence presumably renders intensive tillage ineffective as a method of sawfly control. Four of the eight fields bordering untilled fallow had fewer sawfly-cut stems than the neighboring intensely tilled fields. This decrease in sawfly-cut stems can be partially explained by the increase in sawfly parasitism seen in fields bordering untilled fallow.

Table 3. Depth of wheat stem sawfly stubs in four untilled fields in Broadwater Co., Montana in 2001

Field	Stub age (months)	Total stubs with apex not soil-covered	Total stubs with apex soil-covered	Avg. depth $\pm$ SEM of buried stubs (mm)
A	5-6	27	48	5.2 $\pm$ 0.9
B	5-6	28	47	4.8 $\pm$ 1.4
C	17-18	18	57	7.2 $\pm$ 2.1
D	17-18	21	54	7.7 $\pm$ 1.3

There was no difference in sawfly parasitism between fields that bordered minimally tilled and untilled summer fallow (Table 2). Minimally tilled summer fallow, in which >75% of the stubble remains on the soil surface, is similar to untilled summer fallow in that few parasitoids are buried. Minimum tillage that exposes sawfly stubs on the soil surface showed potential as a control practice (Holmes and Farstad 1956). Freezing and desiccation are important mortality factors for sawfly larvae in exposed stubs (Salt 1946, 1961). Although there is high mortality in exposed stubs (Morrill et al. 1993), current tillage methods do not expose enough soil-free stubble to affect sawfly populations the following year (Goosey 1999).

In the semiarid northern Great Plains, water availability is a major factor limiting plant growth (Willis et al. 1983). Managing fallow land with intensive tillage leaves the soil surface free of residue and increases water loss and soil erosion (Young et al. 1983). Minimum tillage and chemical fallow increase soil surface residue, thus decreasing evaporation and run-off (Wiese et al. 1967), decreasing soil erosion and increasing moisture by trapping snow (Larney et al. 1994). The developments of a wide variety of new and improved herbicides (Wiese 1983) and of new seeding equipment capable of penetrating heavy crop residue (Larney et al. 1994) have reduced the need for tillage. No-till management of fallow land in Montana has increased from an estimated 228,000 acres in 1991 to 456,000 acres in 1998 (CORE 4 Conservation, 2001).

Producers substituting minimum tillage operations in favor of chemical fallow should see no increase in sawfly-cut stems, and no reduction in sawfly parasitism. Intensive tillage is not an effective sawfly control practice and was detrimental to sawfly parasitoids. Replacing intensive tillage with minimum tillage or chemical fallow should result in a cumulative increase in sawfly parasitism over time. Therefore, it seems probable that an overall decrease in sawfly-cut stems, used by producers to determine the extent of their sawfly problems, should result.

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