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Incorporating sheep into dryland grain production systems I. Impact on over-wintering larva populations of wheat stem sawfly, *Cephus cinctus* Norton (Hymenoptera: Cephidae)

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Abstract

Wheat stem sawfly (WSS), *Cephus cinctus* Norton (Hymenoptera: Cephidae) is the most damaging insect pest to Montana's $ 1 billion dollar per year grain industry. Current WSS control methods are either expensive, reduce wheat yields, or are not effective. Our objective was to compare burning, grazing, tilling, trampling and clipping wheat stubble fields on over-wintering WSS larval populations. Treatments were evaluated in three experiments using a randomized complete block design and four replications at each site. Eight, six, and two sites were used for Experiments 1, 2, and 3, respectively. Contrast statements were used to make pre-planned comparisons among treatments. For Experiment 1, treatments were fall tilled, fall grazed, spring grazed, fall and spring combined (Fall/Spr) grazed, and an untreated control. Five mature ewes were confined with electric fence to 111 m^2 plot for 24 h in the fall and spring grazed treatments resulting in a stocking rate of 452 sheep d/ha. For Fall/Spr, the stocking rate was 904 sheep d/ha. For Experiment 2, treatments were fall grazed, fall burned, fall tilled, and an untreated control. In Experiment 3, treatments were fall trampled, spring trampled, Fall/Spr trampled, hand clipped to a stubble height of 4.5 cm, and an untreated control. Trampled treatments were done at the same stocking rates as grazing treatments but sheep were muzzled to prevent intake. Wheat stem sawfly larval numbers were collected in the fall and spring, pre- and post-treatment, respectively, by collecting all plant material from three, 0.46 m lengths of row and counting the number of live larvae present. In Experiment 1, WSS mortality was greater ($P < 0.01$) for the mean of all grazed treatments (68.4%) than either control (43%) or tilled (47%) plots. Mortality did not differ ($P = 0.75$) between fall (67%) and spring (64%) grazed plots but was greater ($P = 0.02$) for Fall/Spr (74%). In Experiment 2, larva mortality was greater ($P < 0.01$) for fall grazed (63%) than burned plots (52%). In Experiment 3, WSS mortality was greater ($P < 0.01$) for the mean of all trampling treatments (57%) than either control (33%) or clipped (32%) plots. Mortality did not differ ($P > 0.25$) between fall (54%) and spring trampling (47%) but was greater ($P = 0.01$) for Fall/Spr (70.6%). No differences ($P > 0.25$) were detected for WSS mortality when grazing was compared to trampling. These results indicate the potential for using grazing sheep to control wheat stem sawfly infestations in cereal grain production systems.

Keywords: Wheat stem sawfly control; Sheep grazing; Tillage; Burning; Trampling

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1. Introduction

Wheat stem sawfly (WSS), *Cephus cinctus* Norton (Hymenoptera: Cephidae), is the most destructive pest to Montana's $ 1 billion per year grain industry, costing producers over $ 30 million per year (Blodgett et al., 1997). Wheat stem sawflies can be found throughout the United States and Canada. However, they are currently only a serious pest to wheat production in the Northern Great Plains of the United States and Canada (Wallace and McNeal, 1966). Originally WSS was only a pest of spring wheat (Davis, 1955; Morrill et al., 1998), however, by the mid-1980s winter wheat was also affected (Morrill et al., 1992). Adult WSS are non-feeding and emerge from the previous year's stubble over a 4–6 week period (Semans et al., 1944; Weiss and Morrill, 1992) making insecticide control impractical. Eggs typically are laid into grass stems. Following emergence, larvae feed inside the elongating wheat stem, which provides protection from predators and insecticides (Skoog and Wallace, 1964; Blodgett et al., 1996). Wheat stem sawfly feeding within the stem disrupts carbohydrate translocation to the developing kernels (Wallace and McNeal, 1966), resulting in a 3–to 10% reduction in head weight (Morrill et al., 1992). Larval notching of stems, commonly called 'cutting', increases lodging of wheat. Lodging and subsequent grain head loss is the primary damage resulting when WSS larvae complete feeding and notch the lower stem to form an over-wintering cell. Although tillage (Goosey, 1999), burning (Farstad, 1944), and parasitoids (Morrill et al., 1998) have been used to control WSS, these methods are either costly or ineffective. Resistant cultivars is the most common method of preventing losses from WSS. However, decreased yield is associated with the solid stemmed trait (Bowman et al., 1996), the only type of documented host plant resistance.

Temperature and moisture are the primary factors that determine the rate of egg development (Ainslie, 1920; Church, 1955). Increased moisture and/or decreased temperatures can hinder or prevent the development of the egg (Ainslie, 1920; Church, 1955). Wheat stem sawfly larvae over-winter in wheat stubble. Wheat-fallow production systems, particularly those managed with zero tillage, leave WSS over-wintering sites undisturbed. Targeting the over-wintering stage of the sawfly for management through sheep grazing, may impact WSS populations by disrupting the over-wintering environment, exposing them to conditions that will result in increased mortality. Hatfield et al. (1999) reported that sheep grazing reduced WSS larval numbers by 78% compared to an untreated control. However, their research was conducted only for 1 year, at one location, and did not compare grazing to fall tillage, burning or investigate the relationship between trampling by sheep and removal of stubble by intake. The objective of our study was to compare the impacts of sheep grazing, fall tillage, trampling, and stubble clipping, in a multi-farm study on over-wintering WSS larval populations.

2. Materials and methods

Experiments were conducted in conjunction with two other studies published in this series (Hatfield et al., 2007a, 2007b). Studies were conducted at eight sites on four farms located in Montana with high WSS infestations to evaluate the effects of various management strategies on over-winter WSS larval mortality. The experimental design was a complete randomized block design, replicated four times at each site. Individual plots were 9 m × 12.3 m and were the experiment unit.

Sites 1 and 2 were located in Stillwater County, south central Montana. Sites 3–8 were located in Toole and Pondera counties, north central Montana. All sites were seeded to winter wheat on grain stubble fields resulting from 2000 (sites 1–4) and 2001 (sites 5–8) crops. Precipitation was 11–32% below average, and the number of frost-free days 6–40% above average during the study (NASS, 2003). Soils were generally classified as an aridic fine-loam (Veseth and Montagne, 1980).

Plots were sampled to determine WSS larval numbers prior to treatment imposition in the fall (September and October) and following completion of treatment in the spring (May), but before adult WSS emergence occurred. Three samples were taken from each plot. A sample consisted of removing all stubble material, including plant crowns, from a 0.46 m length of a single stubble row. Samples were labeled and returned to the laboratory where WSS cut stems were identified and dissected to determine if the stem contained a live WSS larva. Response variables were post-treatment (sampled in spring) live larval numbers and percent WSS mortality larvae in each plot. Calculations for percent mortality were made from the beginning (fall) and ending (spring) data from each plot and were calculated as percent mortality = [(fall samples − spring samples)/fall samples] × 100.

2.1. Experiment 1

Treatments were fall tilled, fall grazed, spring grazed, fall and spring combined grazed (Fall/Spr) and an

Table 1
Experiments, treatments, and numbers of sites, blocks and plots

Experiment	Treatment	Site, blocks, plots
Experiment 1	Fall graze[a]	8, 4, 32
	Spring graze[a]	8, 4, 32
	Fall + spring (Fall/Spr) graze[a]	8, 4, 32
	Control[b]	8, 4, 32
	Tillage[c]	8, 4, 32
Experiment 2	Fall graze[a]	6, 4, 24
	Control[b]	6, 4, 24
	Tillage[c]	6, 4, 24
	Burned[d]	6, 4, 24
Experiment 3	Control[b]	2, 4, 8
	Fall trample[e]	2, 4, 8
	Spring trample[e]	2, 4, 8
	Fall + spring (Fall/Spr) trample[e]	2, 4, 8
	Clipped[f]	2, 4, 8

[a] Sheep grazed 111 m^2 plots for 24 h (48 h for Fall/Spr); fall and spring grazed at 452 sheep d/ha, Fall/Spr grazed at 904 sheep d/ha.
[b] No input control.
[c] Shallow tillage (20 cm) was conducted within 72 h of fall grazing.
[d] Burning was conducted within 72 h of fall grazing.
[e] All sheep were muzzled while occupying a 111 m^2 plot for 24 h (Fall/Spr = 48 h); fall and spring = 452 sheep d/ha, Fall/Spr = 904 sheep d/ha.
[f] Entire plot was clipped in the fall to a 4.5 cm stubble height; conducted within 72 h of fall trampling.

untreated control (Table 1). For the grazing treatments, five mature western white-faced ewes were randomly assigned to each grazed plot. Sheep were kept in plots (111 m^2) with electro-net temporary fence (Premier Fence Systems, Washington, IA) powered by Intellishock 40B energizers (Premier Fence Systems, Washington, IA) and Dura-Start deep cycle batteries (Exide Corp., Reading, PA). The fall and spring grazed plots were grazed for 24 h resulting in a stocking rate of 452 sheep d/ha. The Fall/Spr grazed plots were grazed for 24 h in the fall and again for 24 h in the spring resulting in a stocking rate of 904 sheep d/ha. Tillage was done with a chisel plow. Plots were tilled once in the fall to a depth of approximately 20 cm. Tillage occurred within 72 h of fall grazing.

2.2. Experiment 2

In Experiment 2, the untreated control, fall grazed, and fall tilled treatments were subsets of the control, fall grazed, and tilled treatments imposed in Experiment 1 (Table 1). These treatments, along with the burned treatment, were imposed at six of the eight sites. Plots were burned with a propane brush burner in the fall, within 72 h of the fall grazing treatment.

2.3. Experiment 3

In Experiment 3, the untreated control was a subset of the control used in Experiment 1 (Table 1). The other treatments were fall clipped, fall trampled, spring trampled, and fall and spring combined trampled (Fall/Spr). These treatments were imposed on two of the eight sites. For the clipped treatment, the entire plot was mowed to an average height of 4.5 cm. For fall, spring, and Fall/Spr trampled treatments, sheep were muzzled to prevent grazing. Stocking rates for the trampling treatments were the same as for the grazed treatments.

2.4. Statistical analysis

A randomized complete block design with four blocks per location was used for each experiment. Data were analyzed using the GLM procedure of SAS (1993) with plot as the experimental unit. The study was conducted over a 2-year period at four locations per year. Locations were different each year. Because yearly variation would have been confounded with location and annual variation was not an objective of our study, location and year were combined into one term defined as site. Therefore, in Experiment 1 (for example) variation associated with location (d.f. = 3), year (d.f. = 1) and the interaction (d.f. = 3) were pooled into the site variable with 7 d.f. The model included effects of site, treatment, and site by treatment interaction. Models also included the following contrast statements – Experiment 1: (a) control versus grazed, (b) tilled versus grazed, (c) fall and spring grazed versus Fall/Spr grazed; Experiment 2: (a) control versus burned, (b) burned versus tilled, (c) burned versus fall grazed; Experiment 3: (a) control versus trampled, (b) clipped versus trampled, (c) fall versus spring trampled, (d) fall and spring trampled versus Fall/Spr trampled. Wheat stem sawfly larval numbers at the beginning of each experiment was tested in each model as a covariable and included when significant ($P \leq 0.05$).

3. Results and discussion

3.1. Experiment 1

Site by treatment interactions were detected ($P = 0.01$; Table 2) for post-treatment WSS live larva numbers. Therefore, these results are presented as the simple effects of treatment within site. No site by treatment interaction was detected ($P = 0.37$) for percent overwinter larval mortality, therefore, main effects of treatment across sites is presented (Table 2).

Table 2
Experiment 1: interaction[a] of site by treatment for post-treatment wheat stem sawfly larva counts per 0.46 m of row and percent over-winter wheat stem sawfly larva mortality[b] in control[c], tilled[d] fall, spring, and fall + spring (Fall/Spr) grazed[e] plots at eight sites[f] in Montana

	Control	Tilled	Grazed			S.E.	Control vs. grazed *P*-value	Tilled vs. grazed *P*-value	Fall vs. spring grazed *P*-value	Fall and spring vs. Fall/Spr grazed *P*-value
			Fall	Spring	Fall/Spr					
Post-treatment larva count										
Site 1	5.1	2.2	2.3	1.3	1.0	0.88	0.01	0.53	0.44	0.45
Site 2	6.5	7.2	3.7	2.8	1.4	1.59	0.05	0.02	0.69	0.36
Site 3	26.4	22.9	22.2	9.1	11.8	3.01	0.01	0.01	0.01	0.26
Site 4	28.0	27.2	16.8	8.9	12.4	2.57	0.01	0.01	0.05	0.89
Site 5	1.8	2.5	2.7	2.4	2.1	1.42	0.73	0.92	0.82	0.77
Site 6	3.1	3.2	2.9	2.0	2.3	0.74	0.41	0.33	0.33	0.88
Site 7	1.1	1.3	1.1	1.9	1.4	0.65	0.65	0.86	0.41	0.89
Site 8	5.1	5.5	3.1	4.7	2.0	0.18	0.27	0.26	0.24	0.28
Mortality (%)	43.4	46.6	67.2	64.0	73.9	4.07	0.01	0.01	0.75	0.02

[a] Site × treatment interaction was detected ($P < 0.01$).
[b] No site × treatment interaction was detected ($P > 0.22$).
[c] No input control.
[d] Shallow tillage (20 cm) was conducted within 72 h of fall grazing.
[e] Sheep grazed 111 m^2 plots for 24 h (48 h for Fall/Spr); fall and spring grazed at 452 sheep d/ha, Fall/Spr grazed at 904 sheep d/ha.
[f] Sites located in Toole, Pondera, and Stillwater counties.

Post-treatment WSS live larval numbers were greater ($P < 0.04$) for control than grazed (fall, spring, and Fall/Spr) at four sites and did not differ ($P > 0.27$) at the remaining four sites (Table 2). The sites where no differences were detected had relatively low WSS infestations. Larva mortality was greater ($P = 0.01$) for grazed than control treatments (Table 2).

At three of the eight sites, post-treatment larva numbers were greater ($P < 0.05$) in tilled than grazed plots, but post-treatment larval densities between tilled and grazed plots did not differ ($P > 0.25$) at the remaining five sites. Larval mortality was greater ($P = 0.01$) for grazed than tilled treatments (Table 2).

At two of the eight sites, post-treatment larva numbers were greater ($P < 0.05$) for fall than spring grazed treatments. However, at the remaining six sites, larval numbers did not differ ($P > 0.24$) between fall and spring grazed treatments (Table 2). Larval mortality did not differ ($P = 0.75$) between fall and spring grazed treatments (Table 2).

Although post-treatment larval densities did not differ ($P > 0.26$) between Fall/Spr grazed and the mean of fall and spring grazed treatments (Table 2), mortality was greater ($P = 0.02$) for Fall/Spr than the mean of fall and spring grazed treatments (Table 2).

These results agree with those of Hatfield et al. (1999) who reported that compared to a non-grazed control, grazing wheat stubble with sheep in the fall and fall/spring reduced WSS larva numbers in the spring by 60 and 87%, respectively. Although Hatfield et al. (1999) reported that spring grazing and control plots did not differ in WSS larva numbers, spring grazing resulted in a 46% reduction in larval numbers in the spring compared to the non-grazed control.

Goosey (1999) speculated that for tillage to be an effective method of WSS control, soil needed to be removed from around the crown area of the wheat stubble to increase WSS desiccation due to freezing and drying. In field trials using tillage equipment similar to that used in our studies, only 35% of the plant crowns were soil free following tillage (Goosey, 1999). We used standard shallow tillage with sweeps at approximately 20 cm depth, and our results were similar to those of Goosey (1999).

Other studies comparing tillage and grazing on WSS over-wintering larva numbers or mortality are not available. We speculate that compared to tillage, grazing the stubble either breaks the straw stem and disturbs the frass plug the larva has deposited in the stem to protect itself from over-wintering conditions or disrupts the soil around the crown of the plant, increasing larval exposure to greater extremes in environmental conditions.

Goosey (1999), Farstad (1944), and Holmes (1954) emphasized that increased exposure of stems is needed to increase WSS mortality. Church (1955) found that larvae collected in the early spring were physiologically resistant to moisture deficits, and were unaffected by soil moisture level. However, Holmes (1954) reported that to reach 96% WSS mortality, spring wheat stubble must be exposed to environmental conditions between May 25 and June 4. At that time, larvae within the stem were between diapause and pupation and were susceptible to desiccation. In our study, larvae were exposed to cold temperatures, less than 0 °C, as well as dry winter conditions. The fact that fall and spring grazed treatments did not differ in WSS mortality may indicate that, at the stocking rates used in our study, season of grazing may not be a factor in WSS mortality. Hatfield et al. (1999) also reported no difference in WSS mortality between fall and spring grazed plots. One possible explanation for the increased WSS mortality in the Fall/Spr grazed plots compared to fall and spring is the higher stocking rate used in dual season grazing.

Both Mulholland et al. (1976) and Thomas et al. (1990) concluded that cereal stubble with green weedy material was an acceptable grazing resource for sheep when stocked at 330 and 420 sheep d/ha, respectively. The stocking rate for our study was 452 sheep d/ha for the fall and spring treatments, similar to that used by Thomas et al. (1990). Given the similar stocking rates, we conclude that the levels of WSS mortality noted on our study, was accomplished within the realm of reasonable stocking rates on grain stubble used for sheep production. However, the question of similar stocking rates but different durations and intensities of grazing has not been addressed by our current research.

3.2. Experiment 2

Site by treatment interactions were not detected ($P > 0.25$) for all of the variables measured in Experiment 2, therefore main effects of treatments across sites are presented. Post-treatment larva numbers and mortality did not differ ($P > 0.63$) for the comparisons of burned versus control or burned versus tilled (Table 3). Post-treatment WSS larva numbers were lower ($P = 0.01$) and over-wintering larva mortality greater ($P = 0.01$) in fall grazed than burned treatments.

Burning, tillage, and the untreated control did not differ in WSS mortality, indicating insufficient disruption of the over-wintering WSS environment to cause larval desiccation or other environmental factors that increase mortality. Burning does not disrupt the soil surface, which may be key to enhance over-wintering desiccation of WSS, and soil is not heated to temperatures adequate to kill larvae below the soil surface (Salt, 1947; Church, 1955). Salt (1946, 1947) and Church (1955) concluded that WSS larvae can withstand high temperatures for long periods of time without desiccating. The lack of disruption of the soil around the plant crown in the burned plots may, in part, explain the lower mortality in burned than grazed plots.

3.3. Experiment 3

Site by treatment interactions were detected ($P < 0.02$) for post-treatment WSS larval numbers for Experiment 3, therefore, results are presented as the simple effects of treatment within site (Table 4). Site by treatment interactions were not detected ($P > 0.90$) for percent mortality (Table 4). Therefore, main effects of treatments across sites are presented.

The mean of the combined trampling treatments had lower ($P = 0.01$) post-treatment larval numbers than control or clipped treatments at site 4, but did not differ ($P > 0.19$) at site 8 (Table 4). Larva mortality was greater ($P < 0.01$) for the combined trampling treatments than control or clipped treatments. Post-treatment larva numbers and mortality did not differ ($P > 0.44$) between fall and spring trampled treatments. Post-treatment larva numbers were lower ($P = 0.06$) for Fall/Spr than the mean of the fall and spring treatments at site 4, but did not differ ($P = 0.17$) at site 8. Over-wintering larval mortality was greater ($P = 0.01$) for Fall/Spr than the mean of fall and spring trampled treatments (Table 4).

Table 3
Experiment 2: post-treatment wheat stem sawfly larva counts[a] per 0.46 m of row, and percent over-winter mortality[a] in control[b], tilled[c], burned[d] and fall grazed[e] plots at eight combined sites[f] in Montana

	Control	Tilled	Burned	Grazed	S.E.	Burned vs. control P-value	Burned vs. tilled P-value	Burned vs. grazed P-value
Post-treatment larva count	10.3	9.4	9.3	6.9	0.92	0.87	0.66	0.01
Mortality (%)	45.0	47.6	51.9	63.1	4.86	0.97	0.63	0.01

[a] No site × treatment interaction was detected ($P > 0.25$).
[b] No input control.
[c] Shallow tillage (20 cm) was conducted within 72 h of fall grazing.
[d] Burning was conducted within 72 h of fall grazing.
[e] Sheep grazed 111 m^2 plots for 24 h in the fall.
[f] Sites located in Stillwater, Toole and Pondera counties.

Table 4
Experiment 3: interaction[a] of site by treatment for post-treatment wheat stem sawfly larva counts per 0.46 m of row and percent over-winter wheat stem sawfly larva mortality[b] in control[c], clipped[d], fall, spring and fall + spring (Fall/Spr) trampled[e] plots at two sites[f] in Montana

	Control	Clipped	Trampled			S.E.	Control vs. trampled P-value	Clipped vs. trampled P-value	Fall vs. spring trampled P-value	Fall and spring vs. Fall/Spr trampled P-value
			Fall	Spring	Fall/Spr					
Post-treatment larva count										
Site 4	28.0	28.9	19.1	20.2	12.8	2.55	0.01	0.01	0.80	0.06
Site 8	4.9	5.1	2.9	4.6	2.1	1.26	0.18	0.19	0.51	0.17
Mortality (%)	32.8	32.3	54.3	46.9	70.6	7.50	0.01	0.01	0.45	0.01

[a] Site × treatment interaction was detected ($P < 0.02$).
[b] No site × treatment interaction was detected ($P > 0.28$).
[c] No input control.
[d] Entire plot was clipped in the fall to a 4.5 cm stubble height; conducted within 72 h of fall trampling treatments.
[e] All sheep were muzzled while occupying a 111 m^2 plot for 24 h (Fall/Spr = 48 h); fall and spring trample = 452 sheep d/ha, Fall/Spr = 904 sheep d/ha.
[f] Sites located in Toole and Pondera counties.

When the graze treatments were compared within season to the trample treatments no differences were detected ($P > 0.36$) except spring grazed had a lower ($P = 0.01$) post-treatment larva number than spring trampled at site 4 (Table 5). Graze and trample treatments did not differ ($P > 0.25$) in percent mortality (Table 5).

Table 5
Experiment 3: site × treatment interactions for post-treatment[a] wheat stem sawfly larva counts per 0.46 m of row and percent over-winter mortality[b] of wheat stem sawfly larva for grazed[c] compared to trampled[d] treatments at two sites[e] in Montana

	Grazed	Trampled	S.E.	P-value
Post-treatment				
Site 4				
Fall	16.8	18.8	2.01	0.49
Spring	8.9	20.3	2.01	0.01
Fall/Spr	12.4	12.8	2.01	0.89
Site 8				
Fall	3.1	1.8	1.06	0.36
Spring	4.7	5.4	0.92	0.57
Fall/Spr	2.0	2.3	1.06	0.86
Mortality (%)				
Fall	57.4	45.5	7.45	0.25
Spring	46.1	47.9	6.97	0.85
Fall/Spr	72.5	69.6	7.46	0.78

[a] Site × treatment interaction ($P = 0.01$).
[b] No site × treatment interaction was detected ($P = 0.56$).
[c] Sheep grazed 111 m^2 plots for 24 h (48 h for Fall/Spr); fall and spring grazed at 452 sheep d/ha, Fall/Spr grazed at 904 sheep d/ha.
[d] All sheep were muzzled while occupying a 111 m^2 plot for 24 h (Fall/Spr = 48 h); fall and spring trample = 452 sheep d/ha, Fall/Spr = 904 sheep d/ha.
[e] Sites located in Toole and Pondera counties.

Trampling disrupts the soil surface around the roots and causes damage to the stems of the wheat plants. Church (1955) found temperature and moisture to be the prime factors obstructing larval development. The hoof action of the sheep "churn" the soil near the roots where the larvae over-winter, loosening the soil so that it is not as effective for insulating the WSS larvae. Because trampling may be as, or more important than consumption, in reducing larva populations other options of WSS control may be possible. For example, a combination of grazing and winter-feeding of hay on fallow ground may result in sufficient hoof action to drastically reduce WSS larva numbers past the levels noted in our study.

4. Conclusions

Sheep can be used as a tool in an integrated pest management system to reduce wheat stem sawfly numbers. Although more research is needed, particularly on large commercial scale grain operations, results are promising. To fully utilize sheep to control insect or weed infestations, it requires that grain and sheep producers both view the animal as a biological control agent rather than a grazing animal for the sole use of producing food and fiber.

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