Evaluation of Alfalfa Weevil (Coleoptera: Curculionidae) Densities and Regrowth Characteristics of Alfalfa Grazed by Sheep in Winter and Spring[1]

Hayes B. Goosey,[2] Patrick G. Hatfield, Sue L. Blodgett[3] and S. Dennis Cash

Department of Animal and Range Sciences, Linfield Hall, Montana State University, Bozeman, MT 59717 USA

J. Entomol. Sci. 39(4): 598-610 (October 2004)

Abstract Fall regrowth of alfalfa, *Medicago sativa* (L.), serves as a major source of winter pasture for Montana sheep producers. In years of drought, alfalfa fields are extensively winter/spring grazed; however, the impact on crop health is unknown. Alfalfa paddocks were continuously grazed for 95 d in 2002 and 98 d in 2003 during winter and spring to determine the impact on spring and summer alfalfa regrowth, nutrient quality characteristics, and alfalfa weevil, *Hypera postica* Gyllenhal, densities. Grazed and non-grazed forage yield, crude protein (%), and acid and neutral detergent fibers (%) did not differ at harvest ($P > 0.17$) during either study year. Acid and neutral detergent fibers (kg/ha) were greater ($P < 0.05$) in non-grazed compared to grazed plots during 2002-2003. Alfalfa weevil densities were lower in grazed than non-grazed plots ($P < 0.03$) over four sampling dates during both study years. Winter/spring sheep grazing appears to offer potential for alfalfa weevil management without compromising yield or nutritive factors of subsequent alfalfa production.

Key Words *Medicago sativa,* alfalfa weevil, sheep, integrated pest management, sustainable agriculture

Alfalfa, *Medicago sativa* (L.), is grown on approximately 10.6 million ha in the United States (Bailey 1994) with a 1998 estimated on-farm value of $5 billion (Radcliffe and Flanders 1998) and represents the foremost forage crop in many semiarid and temperate states (Allen et al. 1986b, Bailey 1994). Two biological stressors (insects and weeds) combined with poor field management are primarily responsible for reduced alfalfa production (Latheef et al. 1988). The alfalfa weevil, *Hypera postica* Gyllenhal, is economically the most damaging phytophagous pest of alfalfa in the United States (Blodgett et al. 2000).

Montana sheep producers often rely on fall regrowth of alfalfa as a source of fall and winter pasture. Fall regrowth also is utilized as overwintering habitat by the adult alfalfa weevil (Dively 1970, Dowdy et al. 1986), which hibernates in leaf litter or around plant crowns (Blodgett 1996). In the southern U.S., the majority of weevil eggs are oviposited in alfalfa regrowth during fall and winter months, making fields with copious fall regrowth more attractive (Berberet et al. 1980). However, in colder northern states, such as Montana, temperatures restrict weevil winter activity and little to

[1]Received 01 December 2003; accepted for publication 08 February 2004.
[2]Address all inquiries (email: hgoosey@montana.edu).
[3]Department of Entomology, Montana State University.

no oviposition occurs during winter months (Blodgett et al. 2000). Because alfalfa weevil adults aestivate during summer, emerging in fall, they are in a resting state when temperatures are low during winter.

Multiple tactics have been examined to manage alfalfa weevil populations and limit damage with varied results. Alfalfa weevil tolerant cultivars currently available to producers often do not provide sufficient protection from weevil larval damage to justify their use (Blodgett et al. 2000). Biological agents have reduced weevil populations below economic thresholds in the eastern U.S. (Richardson et al. 1971); however, their impact has been marginal in the western U.S. (Van den Bosch 1972, Kingsley et al. 1993, Brewer et al. 1998, Radcliffe and Flanders 1998). Insecticides that target alfalfa weevil larvae are used on approximately 34% of the alfalfa acreage in the U.S. (Bailey 1994). However, insecticide use is costly and requires intensive field monitoring, by producers, to determine when a treatment is economically justifiable.

Cultural practices for weevil management include late fall (Dowdy et al. 1992) and early spring harvest (Essig and Michelbacher 1933, Harper et al. 1990), burning (Bennett and Luttrell 1965), early harvest with raking (Blodgett et al. 2000) and grazing (Dowdy et al. 1992). Late fall harvest as practiced by Dowdy et al. (1992) reduced weevil eggs by 55% in fall regrowth but did not reduce spring larval numbers compared to unharvested controls. Blodgett et al. (2000) reported early harvest followed by raking reduced alfalfa weevil larval numbers in post harvest stubble by 43% compared to early harvest alone. This tactic represents the only recommended non-chemical means of weevil management in Montana.

Dowdy et al. (1992) reported a 67% reduction in weevil eggs and 25% reduction in spring larval numbers in grazed compared to nongrazed plots in Oklahoma. In northern U.S. states, cold winter temperatures restrict early spring weevil activity and oviposition (Blodgett et al. 2000). Therefore, these researchers speculated that winter/spring grazing will have no impact on spring larval populations. Spring larval populations that damage first cut alfalfa in Montana hatch from eggs oviposited that spring (Blodgett 1996). Early spring harvest, as reported by Essig and Michalebacher (1933), can remove the majority of weevil eggs and young larvae, thus reducing subsequent damage. However, early summer harvesting, before physiological plant maturity, typically has a negative impact on yield. Hard winter grazing of many grass and clover species, as reported by Brougham (1960), can favor regrowth by removing foliar cover thus allowing sunlight to penetrate the canopy and raising soil temperatures favorable for plant growth sooner than in non-grazed or mowed plots.

There is no published literature defining grazing dormant alfalfa with sheep in Montana and the impacts this grazing has on spring regrowth characteristics and alfalfa weevil densities. The objective of this study was to determine the effect of winter through spring sheep grazing on spring re-growth characteristics of alfalfa and change in alfalfa weevil densities in southwestern Montana.

Materials and Methods

Research was conducted during 2 study years, 2002 and 2003, 13 km northeast of Dillon in southwestern Montana. During each study year, 6 non-grazed plots (9.1 × 12.2 m) were randomly located within a 2 or 3-y-old (depending on the study year), 36 ha field of "Geneva" alfalfa. Grazed (9.1 × 12.2 m) plots were established, in the same field, 6.1 m north of each non-grazed enclosure. Plots were located within a fenced 324-ha area designated solely to alfalfa and hay barley production. Sheep had free access to the entire 324-ha area during the grazing period, but plots were established within a 36-ha portion of this area to eliminate bias associated with establishing research plots on different alfalfa cultivars.

Non-grazed enclosures were fenced on 16 October 2001 and 30 September 2002, 95 and 128 d prior to introducing sheep, respectively. Fences remained standing throughout the grazing period. Rambouillet ewe lambs (2002: n = 1,600) and breeding ewes (2003: n = 1,200) were introduced to the experimental field on 19 January 2002 and 5 February 2003 and were removed on 3 May 2002 and 15 May 2003, respectively, resulting in stocking rates of 469 and 363 sheep days per ha, respectively. Pre-graze biomass samples were taken from each plot on 16 October 2001 and 30 September 2002. Post-graze biomass samples were taken from each plot on and 6 May 2002 and 28 May 2003. Biomass samples were collected by removing all plant material from three 0.11 m^2 quadrats per plot, dried at 48°C for 72 h, and weighed to determine dry matter. Plant height and weevil count samples were taken weekly at 4 sampling dates during both study years: 2002 (date 1 = 5 June, date 2 = 12 June, date 3 = 19 June, and date 4 = 26 June) 2003 (date 1 = 5 June, date 2 = 12 June, date 3 = 18 June and date 4 = 25 June).

Spring re-growth characteristics. Mean stem height (cm) was determined by randomly selecting 10 stems from 5 randomly located 0.11 m^2 quadrats per plot on each sample date. Stem damage was determined by cutting 100 stems from 10 random locations in each plot on each sampling date. Each stem was visually inspected for weevil damage and assigned a designation of "yes" or "no" depending on the presence or absence of weevil larval damage. The percentage of plants damaged by weevil larvae was calculated from these data. To determine yield, 3 (45.7 × 50.8 cm) quadrats were hand harvested from each plot using a Stihl HS 75 gas hedge trimmer (Stihl Inc., Virginia Beach, VA) by cutting and harvesting all above ground biomass. Forage samples were dried at 48°C for 72 h to determine dry matter yield. Three stems per yield sample were collected at harvest and bagged separately for plant nutrient analyses (dry matter (%), crude protein (%), acid and neutral detergent fibers (%)) conducted at the Montana State University Oscar Thomas Nutrition Center. Crude protein (kg/ha), and acid and neutral detergent fibers (kg/ha) were calculated by multiplying yield with nutrient concentration. Samples were oven dried and ground to pass a 1.0 mm sieve using a Wiley Mill (Thomas Scientific, USA). Crude protein was calculated using the AOAC Leco combustion method 990.03 (AOAC International 1999) and acid and neutral detergent fibers were calculated using methods of Van Soest et al. (1991). Bloom stage (a visual indicator of plant maturity) was determined by assessing the phenological stage of 100 randomly selected stems per plot on 26 June 2002 and 25 June 2003.

Alfalfa weevil densities. Alfalfa weevil adult and larval densities were determined by collecting one sample, consisting of 20 (180°) sweeps with a 38 cm diameter sweep net, per plot per sampling date.

Statistical analyses. The experimental design was a randomized block with plot as the experimental unit. The GLM procedures of SAS (SAS Institute 2000) were used to compute least squared means to make within date comparisons of treatment stem height, percentage of stems damaged by weevil larvae, and alfalfa weevil larval populations. No data transformations were performed prior to analysis. Least squared means were also calculated to analyze treatment dry matter, crude protein, acid and neutral detergent fibers and for comparing treatment pre- and post-biomass and treatment yield and maturity.

Results and Discussion

Interactions and pre-treatment plot biomass. Year by treatment interactions were detected for all variables ($P < 0.05$) with the exception of dry matter yield. Therefore, data were analyzed and are presented within year. Pre-graze biomass did not differ between grazed and non-grazed plots in either year of study (Table 1).

Spring regrowth characteristics. Forage biomass was reduced 98 percent by grazing during 2001-2002 and 73 percent during 2002-2003 (Table 1). During both study years, plant heights were significantly greater in non-grazed than grazed plots for sampling dates 1 ($P < 0.03$) and 2 ($P < 0.04$); however, no differences were detected for sampling dates 3 ($P > 0.3$) and 4 ($P > 0.14$) (Figs. 1, 2). Further, forage dry matter yields in either study year did not differ between treatments (Table 1). These data indicate that although the alfalfa was grazed into the growing period, plants in grazed plots appeared to have accelerated growth rates so that by 19 June 2002 and 18 June 2003, and thereafter, there were no differences in stem heights. In our study, plant heights were initially greater in the non-grazed than grazed plots because the sheep remained grazing on the experimental field until 3 May 2002 and 15 May 2003. The alfalfa within the non-grazed plots had grown 6 to 10 cm during 2001-2002 and 8 to 13 cm during 2002-2003 before the sheep were removed from the grazed area, which is also reflected by the post-grazed biomass (Table 1). Non-grazed plot biomass increased by 277 kg/ha from 16 October 2001 to 6 May 2002 and by 324 kg/ha from 30 September 2002 to 21 May 2003.

Levels of crude protein (%), or acid and neutral detergent fibers (%) did not differ ($P > 0.16$) between treatments in either study year (Table 1). Levels of crude protein (kg/ha), and acid and neutral detergent fibers (kg/ha) did not differ between treatments during 2001-2002 and crude protein (kg/ha) did not differ during 2002-2003. Levels of acid and neutral detergent fibers correlate with digestibility and animal intake (Van Soest 1994). Relatively high values of either acid or neutral detergent fibers correlate with lower quality feeds. No differences were recorded between these fibers (kg/ha), during 2001-2002, for two reasons: (1) alfalfa weevil larval numbers were not great enough, in non-grazed plots, to reduce forage quality and (2) extensive sheep grazing, in grazed plots, did not reduce forage quality. However, during 2003 greater levels of acid and neutral detergent fibers (kg/ha) were recorded from non-grazed alfalfa (Table 1). We speculate this to be a direct response to numbers of feeding alfalfa weevil larvae in non-grazed plots. Montana's alfalfa weevil economic threshold is 20 larvae per sweep (Blodgett 1996) which was exceeded in non-grazed plots during 2002-2003 (Fig. 3). Feeding weevil populations cause economic losses by consuming plants leaves, which are high in cell solubles (i.e., sugars), and leaving plant stems, which are high in structural carbohydrates (i.e., acid and neutral detergent fibers). Conversely, alfalfa weevil larval numbers were kept below the economic threshold in sheep grazed plots (Fig. 3) and a relative increase in forage quality was the result (Table 1).

Plant percent dry matter was greater ($P < 0.01$) in the non-grazed than grazed plots during both study years (Table 1). We were unable to find peer reviewed literature indicating percent dry matter to be an indicator of plant maturity. However, our

Table 1. Yield, maturity and forage quality of alfalfa paddocks continuously grazed from 19 January through 3 May 2002 and 18 January through 15 May 2003 near Dillon, MT

Treatment	Pre-graze biomass (kg/ha)*	Post-graze biomass (kg/ha)**	DM yield (kg/ha)†	Plants blooming (%)†	DM (%)†	CP (%)†	CP (kg/ha)†	ADF (%)†	ADF (kg/ha)†	NDF (%)†	NDF (kg/ha)†
2001-2002											
Grazed	3410	60	5081	2.5	92.7	23.1	1197	28.1	1460	38.2	1986
Non-grazed	3415	3692	5003	5.0	94.0	22.8	1116	27.6	1350	37.3	1828
S.E.	251.80	193.64	222.26	1.24	0.21	0.41	47.8	0.78	71.1	0.94	98.6
P-value	0.99	<0.01	0.80	0.16	<0.01	0.64	0.25	0.62	0.30	0.50	0.29
2002-2003											
Grazed	2636	711	5559	6.2	93.2	18.9	1015	27.0	1424	37.8	1994
Non-grazed	2509	2833	5926	11.5	93.8	17.4	1071	28.1	1748	39.7	2471
S.E.	84.54	163.45	370.87	0.61	0.05	1.37	105.9	0.73	103.4	0.90	141.3
P-value	0.32	<0.01	0.50	<0.01	<0.01	0.47	0.71	0.30	0.05	0.17	0.04

* 16 October 2001; 30 September 2002.
** 6 May 2002; 21 May 2003.
† 26 June 2002; 25 June 2003.

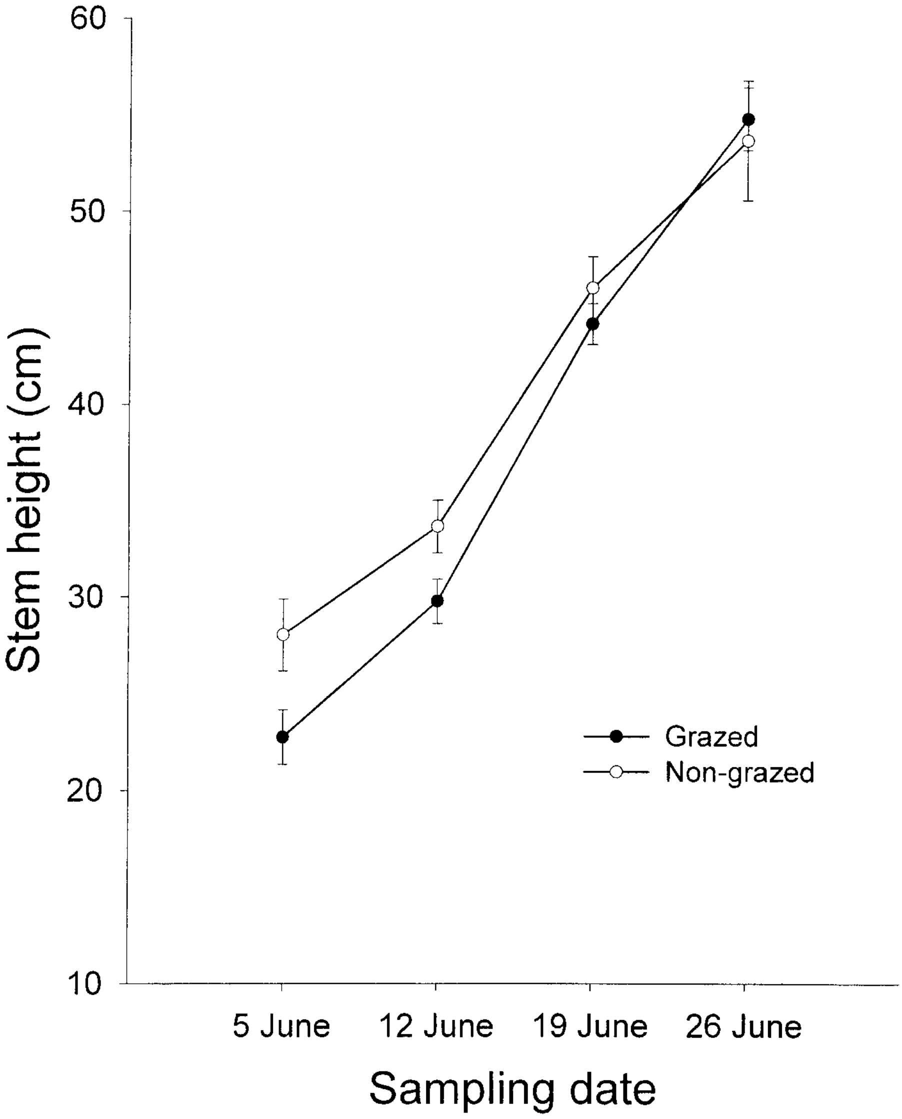

Fig. 1. Comparison of mean alfalfa stem heights across four sampling dates during 2002 in sheep grazed and non-grazed plots where error bars represent the SEM.

data suggest that as plant maturity increases so does plant percent dry matter (Table 1).

Our results agree with Mitchell et al. (1991), who reported no detrimental effects on subsequent alfalfa production in fields grazed by sheep. Mitchell et al. (1991) continuously grazed 20.11 m^2 paddocks with 5 to 7 month old lambs for 60 sheep days

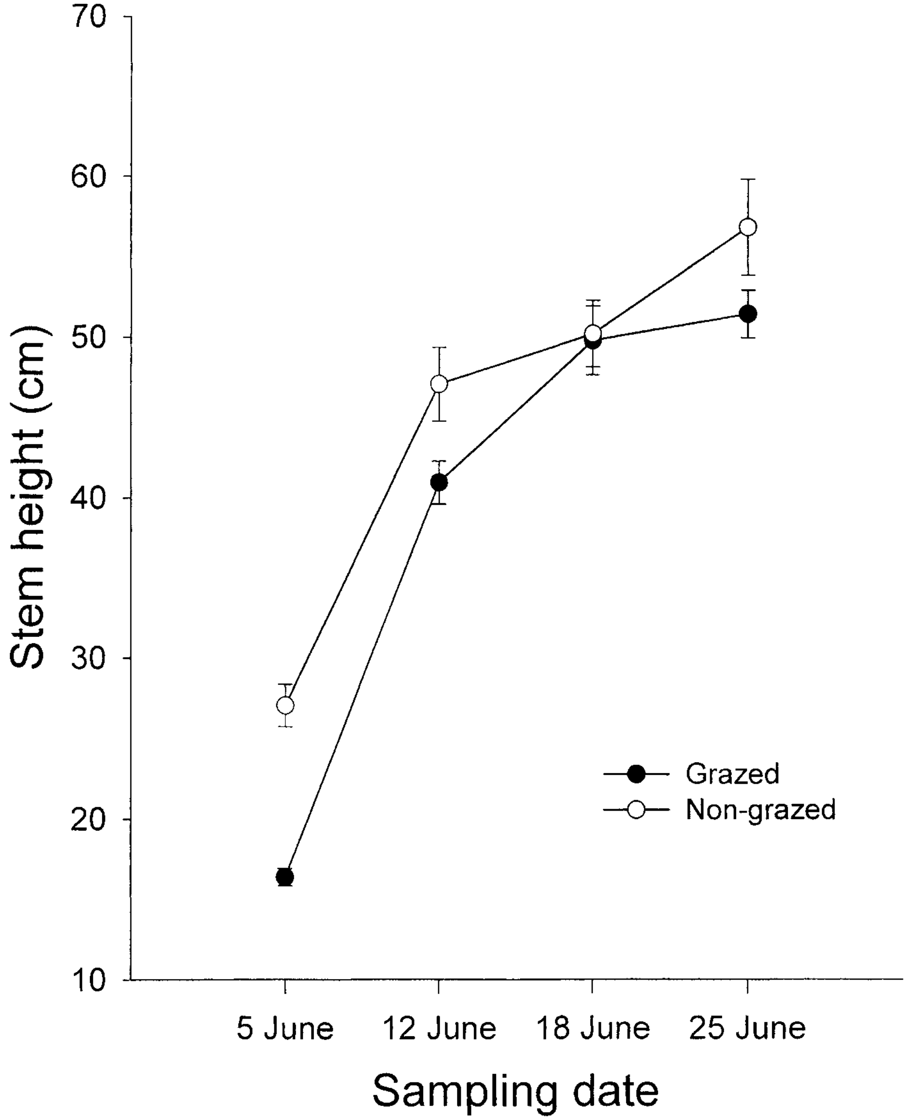

Fig. 2. Comparison of mean alfalfa stem heights across four sampling dates during 2003 in sheep grazed and non-grazed plots where error bars represent the SEM.

during winter months in the Sonoran Desert. Yields reported from grazed paddocks were 5.4 percent greater than yields collected from mowed or non-grazed paddocks. Pelton et al. (1988), who stocked paddocks in northern California at 137 and 69 head of sheep per ha for 2.5 to 3 days in the fall, also reported no statistical yield differ-

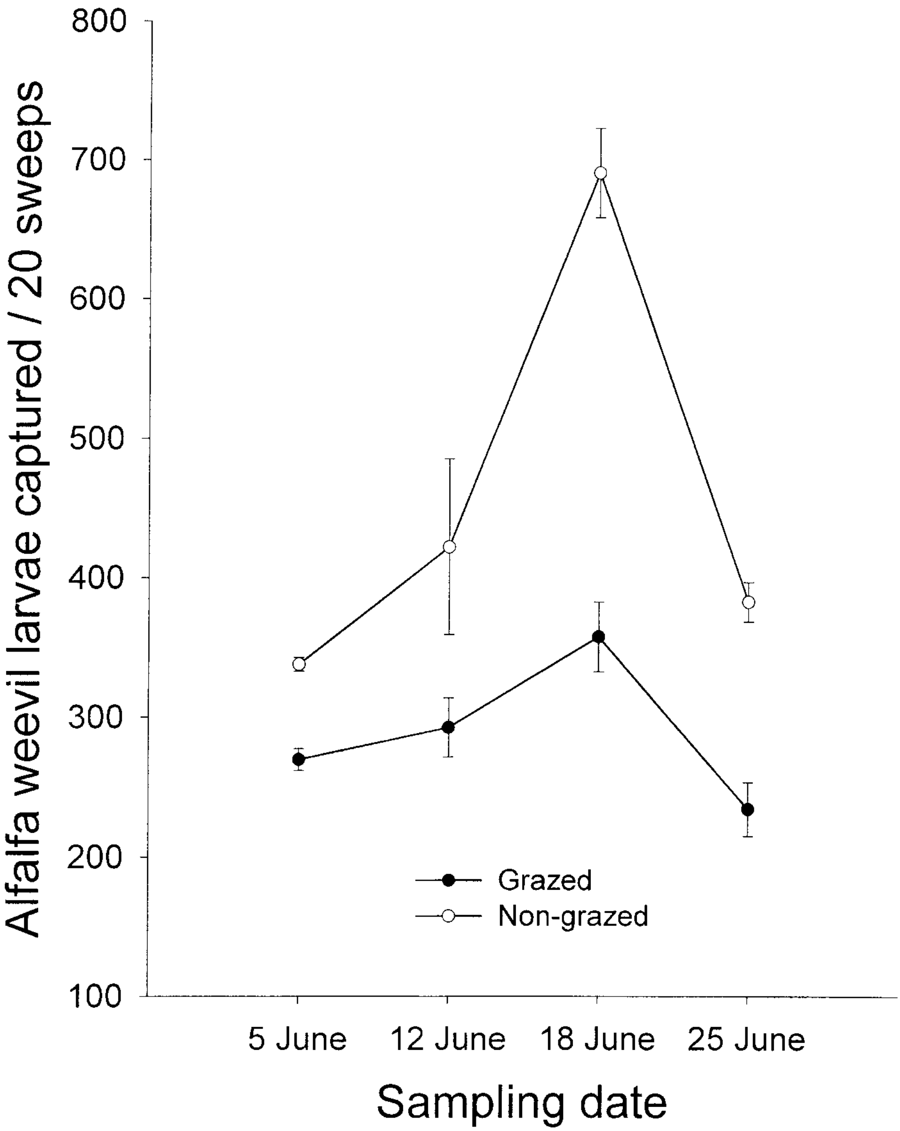

Fig. 3. Results of larval alfalfa weevil sweep net samples taken across four dates during 2003 in sheep grazed and non-grazed plots where error bars represent the SEM.

ences between non-grazed and partial and severe grazed treatments. However, our results are in contrast to those of Allen et al. (1986a) who reported when grazing reduced biomass below 161.93 kg/ha the alfalfa regrowth was negatively impacted. Our 2001-2002 results reported that grazing until 60 kg/ha biomass remained was not detrimental on spring regrowth. Allen et al. (1986a) additionally reported that grazed alfalfa initiated regrowth earlier in the spring, than mowed, while the time to maturation was not increased. It is vital to note that experiments comparing grazing and clipping vary greatly depending on trampling effects, sward characteristics, animal

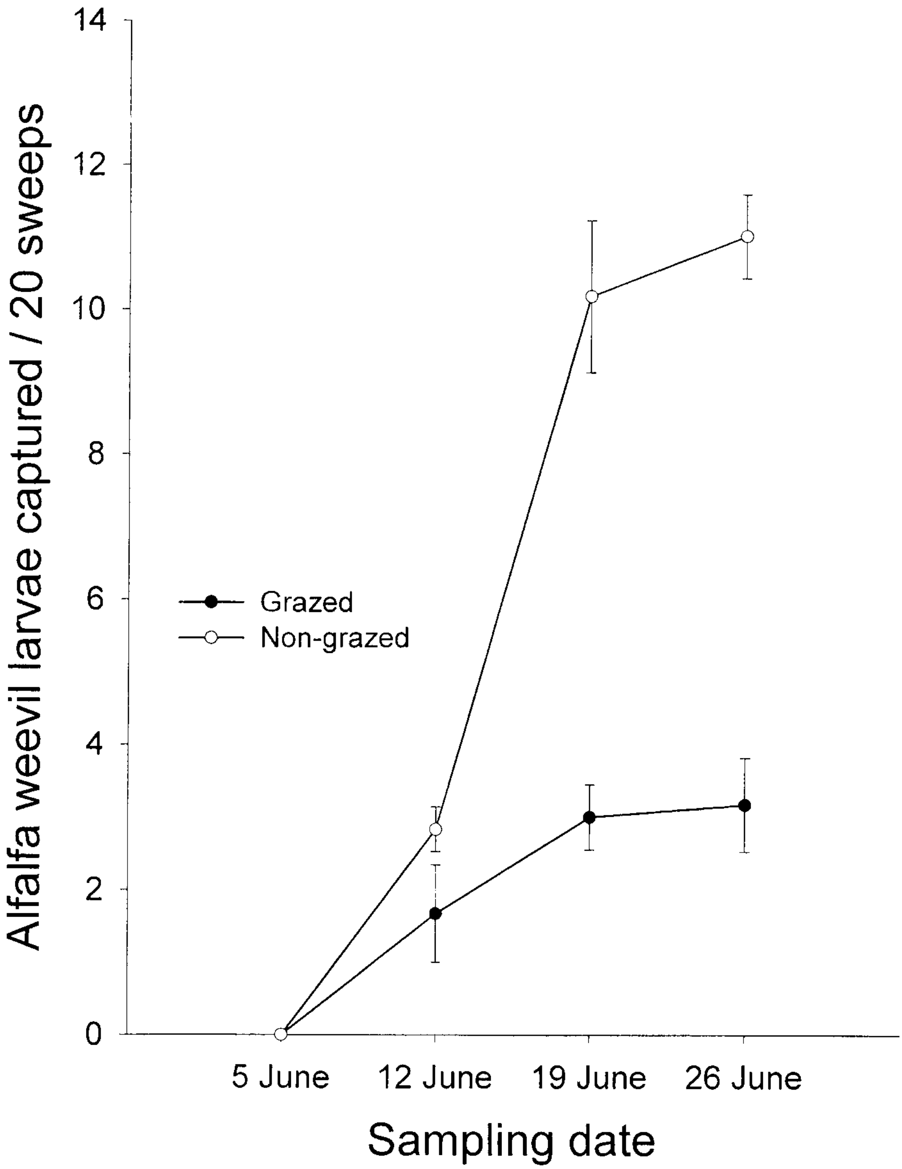

Fig. 4. Results of larval alfalfa weevil sweep net samples taken across four dates during sheep grazed and non-grazed plots where error bars represent the SEM.

species, season of year, location, grazing, and defoliation severity and maintenance of sufficient soil water infiltration rate (Mitchell et al. 1991).

Alfalfa weevil densities. Alfalfa weevil larval numbers did not differ ($P > 0.14$) between treatments, during 2002, on dates 1 and 2, but significantly more ($P < 0.01$)

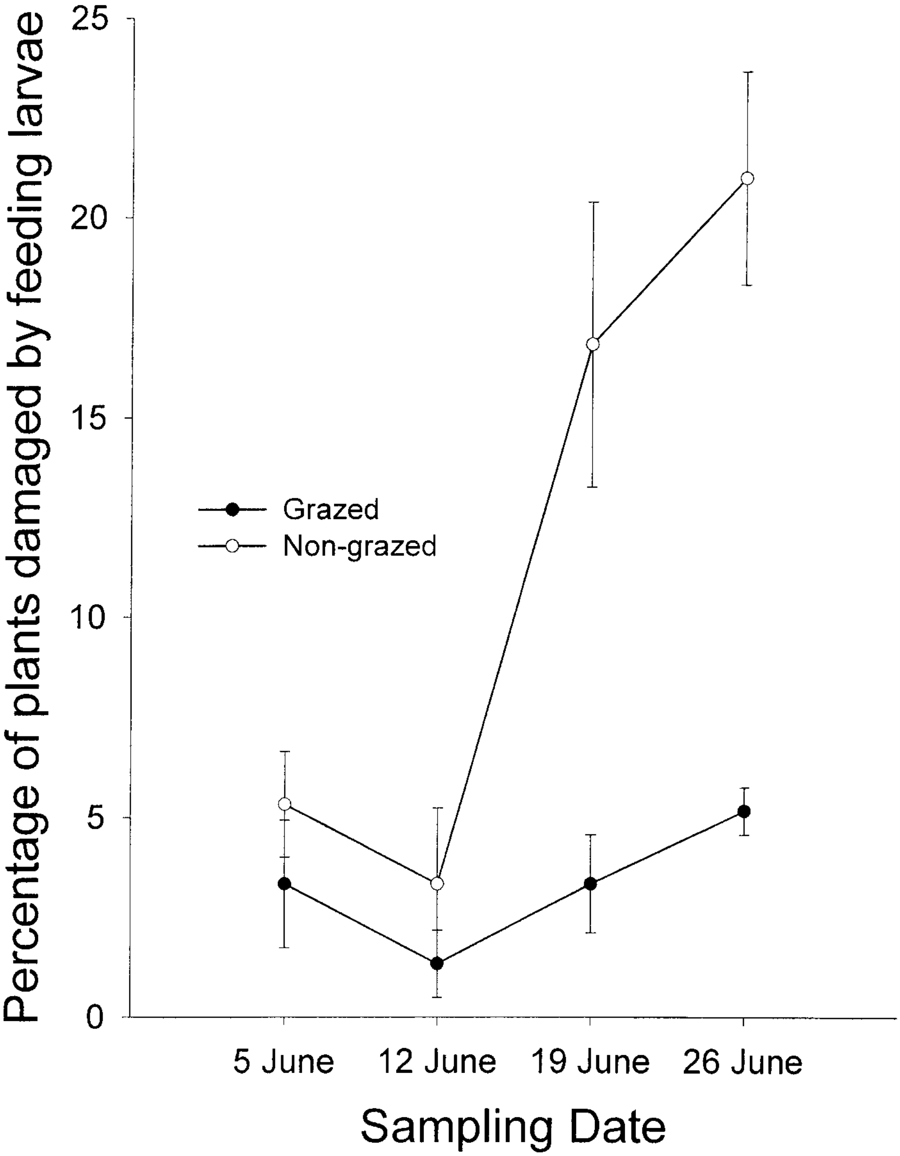

Fig. 5. Results of alfalfa stem damage taken across four dates during 2002 in sheep grazed and non-grazed plots where error bars represent the SEM.

larvae were captured in non-grazed plots on dates 3 and 4 (Fig. 4). During 2003, more ($P < 0.08$) larvae were captured in non-grazed plots on all sampling dates (Fig. 3).

Stem damage did not differ ($P > 0.36$) between treatment during 2002 on sampling dates 1 and 2. However, a greater ($P < 0.01$) level of weevil larval damage was recorded in the non-grazed plots on sampling dates 3 and 4 (Fig. 5). During 2003,

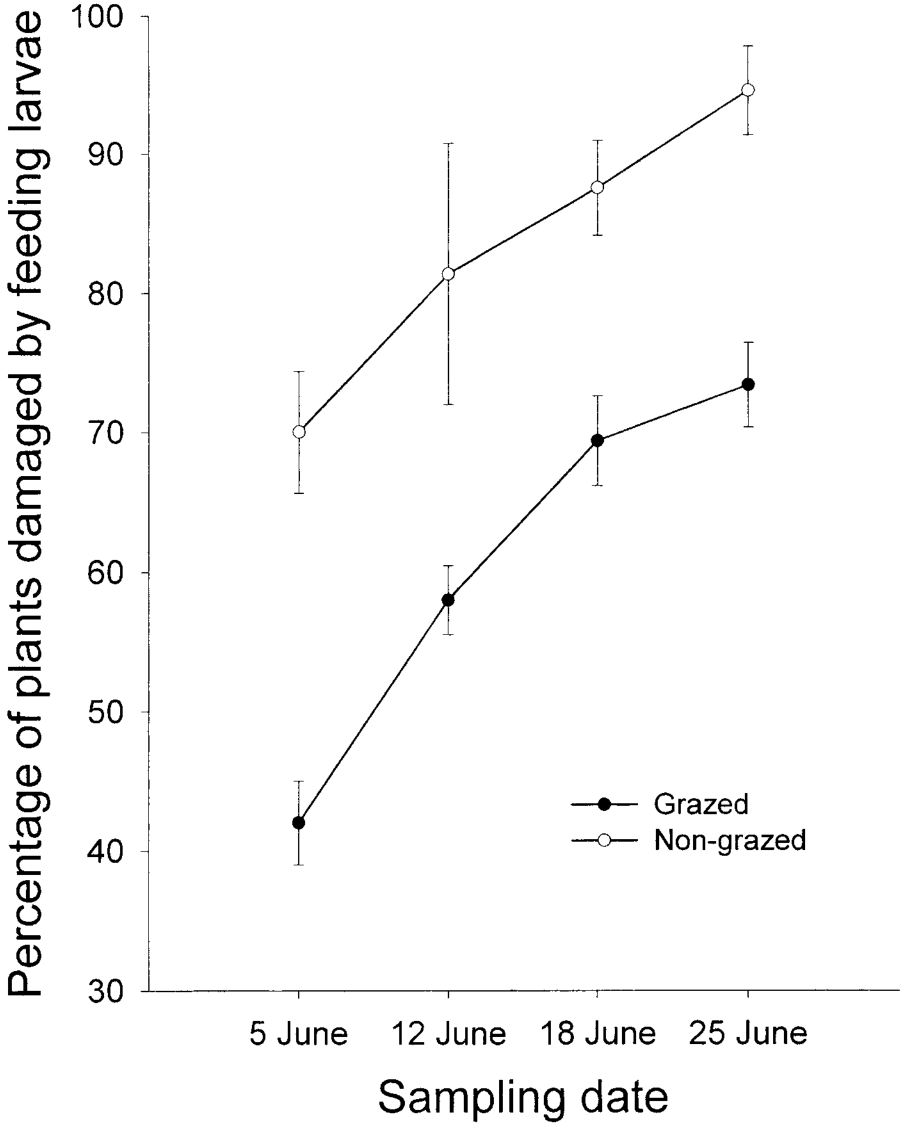

Fig. 6. Results of alfalfa stem damage taken across four dates during 2003 in sheep grazed and non-grazed plots where error bars represent the SEM.

weevil damage was greater ($P < 0.04$) in the non-grazed plots on all sampling dates (Fig. 6).

Dowdy et al. (1992) reported a 25% reduction of alfalfa weevil larvae in grazed compared to non-grazed plots. We recorded values of 40 to 70% reduction in grazed compared to non-grazed plots during two study years. Blodgett et al. (2000) speculated that grazing would have no impact on spring larval numbers in northern climates where there is little to no fall and winter egg lay. However, in our study adult weevil numbers were reduced in grazed plots by 35 to 100% (depending on the sampling date and study year). This reduction may have been a result of reduced biomass, relative humidity and/or temperature, making the grazed areas less attractive for ovipositing alfalfa weevil adults moving into the fields following hibernation. Additionally, biomass was greatly reduced in the grazed plots (Table 1). In this scenario, any alfalfa weevil eggs successfully laid in grazed areas would be quickly consumed by grazing sheep resulting in reduced weevil densities.

These data express potential of grazing alfalfa regrowth as both a source of winter pasture and weevil management in Montana without impacting spring regrowth, crop yields or nutritive characteristics. Similar research has been successfully conducted by Goosey et al. (2002), Hatfield et al. (1999), and Spezzano et al. (2002) whom researched integrating sheep grazing into small grains production to manage pest insect and weed populations. Finally, these data lend themselves to an integrated alfalfa weevil management program and demonstrate the potential of sheep grazing for insect pest management purposes while decreasing production costs and pesticides usage.

Acknowledgments

We gratefully acknowledge sheep and alfalfa producers T. Helle and J. Helle, of Helle Rambouillet (Dillon, MT) for their cooperation and input in conducting this research and T. M. Spezzano for help completing fieldwork and sample processing.

References Cited

Allen, B. G., L. A. Hamilton, D. D. Wolf, J. P. Fontenot, T. H. Terrill and D. R. Notter. 1986a. Yield and regrowth characteristics of alfalfa grazed with sheep I. Spring grazing. Agron. J. 78: 974-979.

1986b. Yield and regrowth characteristics of alfalfa grazed with sheep II. Summer grazing. Agron. J. 78: 979-985.

AOAC International. 1999. AOAC International 16th edition. Gaithersburg, MD.

Bailey, W. C. 1994. Chlorpyrifos use in alfalfa, Pp. 24-29. *In* Witkowski et al. (eds.), The biologic and economic assessment of the field crop usage of Chlorpyrifos. Nat. Agric. Pest. Impact Assessment Program, USDA. 140 pp.

Bennett, S. E. and H. Luttrell. 1965. Alfalfa weevil control by flaming. Tennessee Farm and Home Science Progress Report No. 55, Pp. 6-8.

Berberet, R. C., K. M. Senst, K. E. Nuss and W. P. Gibson. 1980. Alfalfa weevil in Oklahoma: the first ten years. Oklahoma Agricultural Experiment Station Bulletin B-751.

Blodgett, S. L. 1996. Alfalfa weevil. Montana State Coop. Ext. Serv. MontGuide B-17.

Blodgett, S. L., A. W. Lenssen and S. D. Cash. 2000. Harvest with raking for control of alfalfa weevil (Coleoptera: Curculionidae). J. Entomol. Sci. 35: 129-135.

Brewer, M. J., F. B. Peairs and J. D. Donahue. 1998. Alfalfa-insects. *In* J. D. Donahue, M. J. Brewer, F. B. Peairs, and G. L. Hein (eds.), High Plains Integrated Pest Management Guide for Colorado, Western Nebraska and Wyoming No. 564A. Colorado State University, Fort Collins.

Brougham, R. W. 1960. The effects of frequent hard grazings at different times of the year on the productivity and species yields of a grass-clover pasture. N. Z. J. Agric. Res. 3: 125-136.

Dively, G. P., Jr. 1970. Overwintering alfalfa weevil eggs in three stages of alfalfa growth in New Jersey. Ann. Entomol. Soc. Am. 63: 1213-1216.

Dowdy, A. K., R. C. Berberet and J. L. Caddell. 1986. Population densities of alfalfa weevil, *Hyper postica* (Coleoptera: Curculionidae), with varied fall planting dates for alfalfa. J. Econ. Entomol. 79: 790-796.

Dowdy, A. K., R. C. Berberet, J. F. Stritzke, J. L. Caddell and R. W. McNew. 1992. Late fall harvest, winter grazing, and weed control for reduction of alfalfa weevil (Coleoptera: Curculionidae) populations. J. Econ. Entomol. 85: 1946-1953.

Essig, E. O. and A. E. Michelbacher. 1933. The alfalfa weevil. California Univ. Agr. Exp. Stn. Bull. 567.

Goosey, H. B., T. M. Spezzano, P. G. Hatfield, S. L. Blodgett, P. M. Denke and R. W. Kott. 2002. Using sheep in grain production systems to reduce pesticide use: I: Control of wheat stem sawfly infestations in wheat stubble. Proc. West. Sec. Amer. Assoc. Anim. Sci. Vol. 53.

Harper, A. M., B. D. Schaber, T. P. Story and T. Entz. 1990. Effect of swathing and clear-cutting alfalfa on insect populations in southern Alberta. J. Econ. Entomol. 83: 2050-2057.

Hatfield, P. G., S. L. Blodgett, G. D. Johnson, P. M. Denke, R. W. Kott and M. W. Carroll. 1999. Sheep grazing to control wheat stem sawfly, a preliminary study. Sheep & Goat Research Journal. 15: 159-160.

Kingsley, P. C., M. D. Byran, W. H. Day, T. L. Burger, R. J. Dysart and C. P. Schwalbe. 1993. Alfalfa weevil (Coleoptera: Curculionidae) biological control: Spreading the benefits. Environ. Entomol. 22: 1234-1250.

Latheef, M. A., J. L. Caddel, R. C. Berberet and J. F. Stritzke. 1988. Alfalfa production as influenced by pest stress and early first harvest in Oklahoma. Crop Prot. 7: 190-197.

Mitchell, A. R., J. N. Guerrero and V. L. Marble. 1991. Winter sheep grazing in the irrigated Sonoran Desert: II. Soil properties and alfalfa regrowth. J. Prod. Agric. 4: 226-426.

Pelton, R. E., V. L. Marble, W. E. Wildman and G. Peterson. 1988. Fall grazing by sheep on alfalfa. Cal. Agric. Vol. 4-5.

Radcliffe, E. B. and K. L. Flanders. 1998. Biological control of alfalfa weevil in North America. Integrated Pest Management Reviews 3: 225-242.

Richardson, R. L., D. E. Nelson, A. C. York and G. G. Gyrisco. 1971. Biological control of the alfalfa weevil *Hyper postica* (Coleoptera: Curculionidae) in New York. Can. Entomol. 103: 1653-1658.

SAS Institute. 2000. SAS/STAT user's guide: statistics. SAS Institute, Cary, NC.

Spezzano, T. M., H. B. Goosey, P. G. Hatfield, S. L. Blodgett, P. M. Denke and R. W. Kott. 2002. Using sheep in grain production systems to reduce pesticide use: Comparing stubble grazing with tillage and burning on weed and soil characteristics. Proc. West. Sec. Amer. Assoc. Anim. Sci. Vol. 53.

Van den Bosch, R. 1972. Prospects for biological control of alfalfa weevils in California. Proc. 1972 California Alfalfa Symposium, Fresno, CA, Pp. 8-13.

Van Soest, P. J., J. B. Robertson and B. A. Lewis. 1991. Methods of dietary fiber, NDF, and non-starch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74: 3583.

Van Soest, P. J. 1994. Integrated feeding systems, Pp. 408-410. *In* P. J. Van Soest (2nd Ed.), Nutritional Ecology of the Ruminant. Cornell Univ. Press, Ithaca, NY.