

The impact of integrating sheep into wheat farming systems to manage wheat stem sawfly Cephus cintus (Hymenoptera: cephidae) and weeds
by Theresa Marie Spezzano

A thesis submitted in partial fulfillment of the requirement for the degree of Master of Science in Animal and Range Sciences
Montana State University
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Abstract:
Wheat stem sawfly (WSS), Cephus cintus Norton, (Hymenoptera: Cephidae) is the most damaging insect pest to Montana's grain industry. Current methods of WSS management are either expensive, reduce wheat yields, or ineffective. The objectives of our experiment were to compare burning, grazing, tilling, trampling and clipping wheat stubble fields in a multi-farm experiment on: 1) overwintering WSS larval populations, 2) changes in soil bulk density, and 3) biomass. The effects of treatments were evaluated in a completely randomized block design on eight sites in Montana with high wheat stem sawfly infestations. Three experiments were conducted (Grazed, Burned, and Trampled) at each site. All treatments were represented within each site and repeated four times. Plots were 9 x 12 m. Wheat stem sawfly, weed, biomass, and soil samples were taken in the fall, prior to treatment imposition, and spring, after treatments were removed. For the graze experiment the treatments were control, fall tilled, fall grazed, spring grazed, and fall and spring combined grazed. All grazing treatments had higher ($P<0.10$) mortality than the other treatments, with fall and spring combined graze having the highest ($P<0.10$) mortality. At seven out of eight sites, there were no differences ($P>0.22$), in percent biomass remaining in till compared to fall graze treatments. At six sites tillage had a higher ($P<0.06$) percent biomass remaining than the combination of fall and spring graze. Burned experiment treatments were control, fall grazed, fall burned, and fall tilled. Percent mortality did not differ ($P=0.39$) between burn and tilled ($P=0.39$). Fall grazed had a higher ($P=0.05$) percent mortality than did burn. At four out of the six sites there were no differences ($P>0.15$) in percent biomass remaining between burn and fall graze. Trampled experiment treatments were control, fall, spring, and fall and spring combined trample, and clip (between 2-7 cm). The combination of the fall and spring trample had the highest mortality compared to all other trample treatments. In all three experiments sheep grazing did not increase ($P<0.10$) soil compaction compared to the control. These data indicate grazing may be an effective tool in wheat stem sawfly and weed management, without negative effects on soil bulk density.

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APPROVAL

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content. English usage, format, citations bibliographic style and consistency, and is ready for submission to the college of Graduate Studies.

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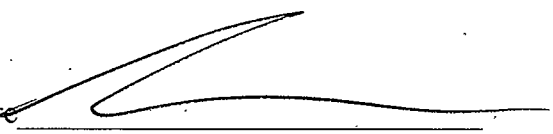
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## ABSTRACT

Wheat stem sawfly (WSS), *Cephus cintus* Norton, (Hymenoptera: Cephidae) is the most damaging insect pest to Montana's grain industry. Current methods of WSS management are either expensive, reduce wheat yields, or ineffective. The objectives of our experiment were to compare burning, grazing, tilling, trampling and clipping wheat stubble fields in a multi-farm experiment on: 1) overwintering WSS larval populations, 2) changes in soil bulk density, and 3) biomass. The effects of treatments were evaluated in a completely randomized block design on eight sites in Montana with high wheat stem sawfly infestations. Three experiments were conducted (Grazed, Burned, and Trampled) at each site. All treatments were represented within each site and repeated four times. Plots were 9 x 12 m. Wheat stem sawfly, weed, biomass, and soil samples were taken in the fall, prior to treatment imposition, and spring, after treatments were removed. For the graze experiment the treatments were control, fall tilled, fall grazed, spring grazed, and fall and spring combined grazed. All grazing treatments had higher ($P<0.10$) mortality than the other treatments, with fall and spring combined graze having the highest ($P<0.10$) mortality. At seven out of eight sites, there were no differences ($P>0.22$), in percent biomass remaining in till compared to fall graze treatments. At six sites tillage had a higher ($P<0.06$) percent biomass remaining than the combination of fall and spring graze. Burned experiment treatments were control, fall grazed, fall burned, and fall tilled. Percent mortality did not differ ($P=0.39$) between burn and tilled ($P=0.39$). Fall grazed had a higher ($P=0.05$) percent mortality than did burn. At four out of the six sites there were no differences ($P>0.15$) in percent biomass remaining between burn and fall graze. Trampled experiment treatments were control, fall, spring, and fall and spring combined trample, and clip (between 2-7 cm). The combination of the fall and spring trample had the highest mortality compared to all other trample treatments. In all three experiments sheep grazing did not increase ($P<0.10$) soil compaction compared to the control. These data indicate grazing may be an effective tool in wheat stem sawfly and weed management, without negative effects on soil bulk density.

# INTRODUCTION

Wheat production is the largest agricultural crop industry in Montana. Montana is ranked 4th in the U.S. for wheat production (NASS, 2003). The wheat industry received a total revenue of $304,487,000 from wheat sales in 2001. In 2001, 1,905,000 hectares of wheat were harvested and 517,600 hectares were in fallow (NASS, 2003). The major challenges to wheat producers in Montana are maintaining soil water and managing pests, including insects, weeds, and plant disease. Blodgett et al. (1997b) in a survey of 2,500 farmers in Montana identified the wheat stem sawfly (WSS), *Cephus cintus* Norton, (Hymenoptera: Cephidae) as the most damaging insect pest in Montana crop production. The WSS is estimated to cost Montana wheat producers over $30 million per year (Blodgett, 1997a).

Most wheat production in Montana is on non-irrigated land (dryland). Summer fallowing is the single most important cultural cropping practice in the semiarid regions of the western United States (Greb, 1981). In the fallow system a field is deliberately left non-cropped to accumulate sufficient soil water to reduce the risk of failure when the next crop is planted. This time lapse usually includes at least one winter and one crop season (Greb, 1981). Fallowing stabilizes crop production in dryland cropping systems by storing soil moisture sufficient to produce the subsequent grain crop. Fallow management is the highest variable cost in small grain production (Johnson et al., 1997). One of the greatest problems in fallow is the prevention of weed growth without increasing soil erosion (Fenster, 1997) or soil bulk density (Canillas and Salokhe, 2001).

Wheat stem sawfly overwinters in stubble fallowed areas. Populations of WSS can be reduced through management of the fallow during the winter.

The null hypotheses for this project were: 1) grazing would not disrupt the overwintering habitat of WSS, therefore not increase WSS mortality compared to other management practices, 2) grazing sheep would not increase soil bulk density (compaction), and 3) grazing would not reduce plant biomass and weeds. The objectives of our study were to compare burning, grazing, tilling, trampling and clipping wheat stubble fields in a multi-farm study on: 1) overwintering WSS larval populations, 2) changes in soil bulk density, and 3) total plant biomass including wheat stubble, volunteer wheat and weeds.

# LITERATURE REVIEW

## Wheat stem sawfly

The first documented infestation of wheat stem sawfly (WSS) was in 1890, in Alameda, California, in Timothy grass (*Phleum pratense)* (Ainslie, 1920). In 1891, researchers suggested that the economic importance of WSS would increase if it abandoned it's original hosts, wild hollow stemmed grasses, in favor of cultivated cereals (Ainslie; 1920). In 1896, it appeared in Canadian wheat (Weiss and Morrill, 1992). Wheat stem sawfly became a major pest to wheat in the northern Great Plains by 1916 (Munro, 1945). In 1948, in Montana 17.4 percent or 312,170 ha of wheat were infested with WSS and in North Dakota, 28.3 percent or 1,077,437 ha of wheat were infested (Davis and Knapp, 1949). The losses in Montana and North Dakota in 1948 were estimated to be three million bushels (Davis and Knapp, 1949). Survey results from 1995 through 1996 in Montana by Blodgett et al. (1997b) estimated losses attributed to WSS at 36,930,000 bushels with only 11.8% of the total farmed acreages surveyed. Wheat stem sawflies can be found throughout the United States and Canada, however they are only a serious pest to the wheat producing areas of the Northern Great Plains in the United State and Canada (Wallace and McNeal, 1966a).

Wheat stem sawflies continue to adapt to wheat (Morrill et al., 1998). Originally, WSS was a pest of spring wheat only because winter wheat usually matured early enough to avoid attack (Davis, 1955; Morrill et al., 1998). However, by

the mid-1980's winter wheat was also affected (Morrill et al., 1994). Comparisons of current and early records by Morrill et al. (1998) indicated that WSS oviposition in the late 1990's began a month sooner than was previously observed, synchronized with the period of vulnerability of winter wheat. There is a range of susceptibility from stem elongation to boot stage (Roberts, 1954).

Life Cycle

Adult WSS emerge from the previous year's stubble over a four to six week period starting in May (Semans et al., 1944; Weiss and Morrill, 1992). Males emerge prior to the females and the majority remain at the crop edge where the most of mating occurs (Holmes and Peterson, 1963, Holmes, 1984).

The female is easily distinguished by a prominent ovipositor (Ries, 1926). Oviposition typically is into the first or second internodes of the primary tillers of the plant. Stem selection for oviposition depends on the stage of plant development as well as stem size (Morrill et al., 1992). The first internodes of the stems must have begun to elongate, but not mature for oviposition to occur. Early WSS adults attack the primary stems, while late emerging adults attack the secondary stems or tillers (Morrill et al., 1992). Primary stem (main stem) and spike appear first and are followed by one or more secondary tillers. Tillers form on the primary stem from buds below ground (Cook and Veseth, 1991). Usually a WSS selecting an oviposition site moves up and down the top leaf, then turns and moves head first down the stem. The female will then insert her saw-like ovipositor, making a small opening in the stem in which to lay her eggs. If the site is unsuitable (she is unable to insert her ovipositor)

the female will spiral down the stem making attempts to oviposit. She will continue moving down the stem until she oviposits or flies away (Holmes and Peterson, 1960).

Wheat stem sawflies are haplo-diploid, or arrhenotokous (Makay, 1955). The males develop from unfertilized (haploid) eggs and females develop from fertilized (diploid) eggs (Makay, 1955). Selective egg fertilization at the time of oviposition determines the sex of the progeny. Male-biased populations may occur if late-emerging females are unable to find mates or if sperm supplies are depleted late in the season (Morrill et al., 2000). Morrill et al. (2000) found sex ratios biased with males emerging from small stubs and females from larger stubs. The females that emerged from larger stems had longer wing lengths and were heavier then those which emerged from smaller stems. The WSS with the longer wing lengths lived longer than others in the study.

Temperature and moisture are the primary factors that determine the rate of egg development (Ainslie, 1920; Church, 1955). Under normal conditions eggs hatch approximately seven days after oviposition (Ainslie, 1920). However, increased moisture and/or decreased temperatures can hinder or prevent the development of the egg (Ainslie, 1920; Church, 1955). Larvae feed on parenchyma and vascular tissue inside the stem, filling the stem with the frass they excrete as they feed. Larvae will also cannibalize other WSS eggs or larvae they encounter (Holmes 1954b). The number of larval instars (developmental stage of the insect between molts) depends on the host plant species (Farstad, 1940). As the larvae mature they migrate down the stem driven by reduced stem moisture and light filtering through the stem as it matures

and dries out (Holmes, 1975). Mature larvae cut a V-shaped groove around the inside of the stem, usually just above the soil surface (Ainslie, 1920). The groove is plugged with frass (Ainslie, 1920). The groove does not sever the stem, but weakens it so it will break off in the wind, just above the soil surface where groove was made (Luginbill and McNeal, 1955). Just below the frass plug the larvae places another plug. This second plug is concave on the upper surface while on the lower surface it is flat (Ries, 1926). Below this plug the larvae spins its cocoon where it will spend the winter. The cocoon is free from the sides of the stem, but is generally attached to the lower surface of the second plug (Ries, 1926). Larvae spend the winter in a diapause or a irreversible resting state within the cocoon inside the stub, below the soil surface. Pupation occurs in the spring after diapause is completed and soil temperatures rise (Morrill et al., 2000). Diapause is a period during which development is suspended and physiological activity is diminished and is only reversed by environmental cues. Adult WSS range in size between 6.37 to 12.7 mm (Wallace and Mc Neal. 1966a).

Economic Loss

Wheat stem sawfly feeding within the stem disrupts carbohydrate translocation to the developing kernels (Wallace and McNeal, 1966a). Morrill et al. (1992) reported 2.8 to 10.1% reductions in head weight from WSS larvae feeding within the stem. This leaves 89.9 to 97.2% of losses from WSS infestation due to lodging. Lodging loss is the primary damage caused by WSS and can be extensive when infestation is wide spread. Lodged wheat heads drop to the ground, shattering the grain which reduces yield, equipment is damaged due to the need to lower the header height

for harvest, and time to harvest is increased due to slower harvest speeds and extra care needed to harvest the lodged wheat.

In the survey of farmers conducted in 1996 and 1997, estimated usage and costs of harvest practices attributed to WSS management were as follows: 28% of farmers surveyed used tillage as a management practice, the average reported cost was $5.50/acre, but ranged from $2 to $25/acre; 25% of the farmers surveyed used swathing as a management practice, the average cost was $6.00/acre but ranged from $4.50 to $8.00/acre; 21% of farmers used custom combining as a management practice, with costs averaging $5.90/acre, and ranged from $1 to $14/acre (Blodgett et al., 1997b).

Biological Practices

Resistant wheat. Resistant (solid stem) varieties of wheat have been shown to be an effective management tool for WSS (Platt et al., 1948; Eckroth and McNeal, 1953). However, these studies only compared hollow stemmed wheat with solid stemmed wheat and but did not compare other management practices. 'Rescue' wheat averaged an 8% yield reduction compared to hollow-stemmed wheat when WSS was not present (Platt et al., 1948). However, the average WSS infestation rate dropped 59% the year 'Rescue' was released (Platt et al., 1948).

In general, yields of solid stem wheat varieties are lower than hollow-stemmed varieties when WSS is not present. Energy that would be allocated to increase kernel size and kernel number in a hollow stem variety is at least partly used in creating the solid stem (McNeal et al., 1965; Hardin, 2001). The degree of solidness can be highly modified by environmental conditions (Eckroth and McNeal, 1954). Shading in the field due to cloud cover and/or excess moisture received by developing plants decreases solidness of the stem (Ecrkoth and McNeil, 1954; Holmes, 1984). A more hollow stem enhances the survival of the WSS within solid stem varieties.

The first two solid-stemmed winter wheat varieties resistant to WSS infestation, 'Rampart' and 'Vanguard,' were developed at Montana State University (Bruckner et al., 2001). Approximately 22% of Montana's winter wheat acreage was planted to these varieties in 2000, and the seeded acreages continue to increase (Bruckner et al., 2001). However these varieties are not immune to WSS infestation. At some sites Bruckner et al. (2001) found heavy infestations of WSS.

In Montana, the most popular spring wheat variety in 2002 was 'McNeal', which accounted for over 39% of the wheat seeded acreage. However, 'McNeal' is vulnerable to WSS. 'Ernest' and 'Fortuna' were the fourth and fifth most popular, respectively, both of these varieties are WSS resistant (Anonymous, 2002).

Tillage. Goosey (1999) found 70% WSS mortality in stems that were free from soil and laying on the soil surface. Soil left on the plant crown can insulate the larvae against the effects of temperature and desiccation. Shallow tillage at depths less than 30 cm is intended to expose plant crowns to unfavorable environmental

conditions, (Farstad, 1941). Farstad (1942) and Callenbach and Hansmeier (1945) reported positive results with shallow tillage as long as crowns were exposed at the surface. They both warned however, if the stubble is buried it is protected from the effects of environmental conditions and desiccation. Wheat stem sawfly larvae become more resistant to desiccation just after the host plant stem is lodged and they secrete their protective cocoon (Goosey, 1999). Goosey (1999) reported higher WSS mortalities (approximately 75% difference) when a rotary harrow was used to increase crown exposure. Therefore, in order for tillage to be an effective form of management care must be taken to increase the exposure of the crowns.

Burning. Burning has been used to manage WSS, however larvae can withstand high temperatures for long lengths of time without desiccating. Criddle (1922) and Farstad (1944) found that field stubble burning was not effective for managing WSS. Salt (1946) found that in September, larvae below the soil surface, can withstand 40° C for up to three days without any mortality. He also found the highest mortalities occurred after the larvae were exposed to 40° C for nine days. Salt (1947) tested whether humidity and temperature could be used to interfere with normal WSS development post diapause. Post-diapause larvae exposed to 35° C for more than 25 days were unable to develop. However, after conditions returned to normal they were able to continue development. What Salt (1947) determined from this research was that there is a critical point in the WSS lifecycle when diapause can reoccur after being broken. Under natural conditions this occurs in the spring

following diapause. There was evidence to suggest that the temperature of 35° C had no ill effect during diapause. However, it does have an ill effect on developing forms such as prepupae and pupae where it produces abnormalities and death (Salt, 1947). However, for both these studies by Salt (1946, 1947) the stubs were removed from the soil. Most of the cut stem is located below the soil surface, which aids in the insulation of the larvae from adverse conditions, including elevated surface temperature.

Parasitoids. In native grasses WSS is attacked by nine species of parasitoids (Holmes et al., 1963). Of these nine species only *Bracon cephi* (Gahan) and *Bracon lissogaster* Muesebeck (Hymenoptera: Braconidae) have been found in wheat (Somsen and Luginbill, 1956). Parasitoids have been slower to adapt to wheat than WSS (Morrill et al., 1998). Parasitism in wild grasses sometimes approached 100%, but usually was less than 2% in wheat (Criddle, 1922; Nelson, 1953; Morrill et al., 1998).

Parasitoids success as a biological control has been sporadic; this may be due to other agricultural practices such as pesticides and weed control (Mohamed et al., 2000). Many parasitoids that are effective in their native environment are not as effective in cultivated fields (Mohamed et al., 2000). Morrill et al. (1998) reported levels of WSS mortality from *Bracon cephi* and *Bracon lissogaster* ranging from 98% in Pondera County, MT to 1% in Stillwater County, MT. They released 200 parasitoid larvae at the edge of each site. Levels of parasitism in WSS have been

determined annually since 1990 in Pondera County, Montana (Morrill et al., 1998). In 1992 through 1993 mortality levels averaged 70 to 79% (Morrill et al., 1994).

The feeding behavior of *B. lissogaster* and *B.cephi* are similar (Somsen and Luginbill, 1956; Holmes et al. 1963). The adult female walks up and down the wheat stem, occasionally tapping the stem with her antenna. When a WSS larva is located she stops, raises her body and remains rigid, possibly detecting WSS larva or movement within the stem. She may remain in this position for hours (Somsen and Luginbill, 1956). She then inserts her ovipositor into the stem paralyzing the larva. Parasitoid eggs are deposited on or near the WSS larva (Somsen and Luginbill, 1956). The eggs adhere to WSS larva. The eggs hatch in approximately 66 hours. Parasitoid larvae feed on the outer surface of the WSS larva, sucking juices from the body through minute lacerations made with its mandibles (Somsen and Luginbill, 1956). The parasite larvae will feed on the WSS larva for approximately 10 d (Holmes et al, 1963). The larvae will then spin a cocoon for pupation followed by adult emergence. Both parasitoids have two complete generations per year in native grasses (Criddle, 1922). In wheat, a partial second generation has been reported for *B. cephi* (Holmes et al., 1963) and a complete second generation for *B. lissogaster* (Somsen and Luginbill, 1956). Harvest is thought to disrupt the emergence of the second generation of *B.cephi*.

Swathing. Swathing is used to cut and windrow WSS infested crops prior to lodging (Butcher, 1945). Swathing has been recommended to prevent losses due to WSS infestations (Criddle, 1922; Callenbach and Hansmeier, 1944; Farstad et al.,

1945). Swathing increases the amount of harvested grain but it does not reduce WSS infestation. Holmes and Peterson (1965) found no reduction in WSS cut stems after swathing. Goosey (1999) found WSS larvae, which are below the swath cut line, are still capable of successfully completing their lifecycle. Swathing may reduce yields and the test weight of the grain if it is done before the grain moisture level is below 35% (Holmes and Peterson, 1965). Swathing is generally recommended for wheat when it reaches the hard dough stage, which occurs at about 30 to 32% moisture (Peel, 1997).

Trap Crops. Trap cropping is a tactic used to make a small perimeter of the field more attractive to the WSS. Ten to 20 foot wide trap strips are planted along the outside of a field where WSS populations are the highest (Butcher, 1945). Seeding is timed to make the trap strip attractive as possible, relative to the crop, then destroying it with the larvae inside to ensure the larvae do not survive (Callenbaugh and Hansmeier, 1945). Producers are reluctant to use this type of trap cropping as a management tactic as it is costly and represents an economic loss to the producer. More often, solid stem winter wheat is seeded around hollow stem spring wheat. Because the majority of eggs are laid at the edge of the field WSS numbers will be reduced due to the lower survival rates in solid stem. There would also be less infestation in the hollow stem spring wheat because of differences in the trap and crop maturity and less WSS migrating to the center of the field.

Morrill et al. (2001) looked at spring and winter wheat traps at widths of 13 m (spring wheat) and 10 m (winter wheat). They evaluated the adult populations of WSS

as a function of distance into the fields. Within the spring wheat fields the project was terminated because the trap strips failed to retain adult sawflies in the first year. In the winter wheat fields the trap strips were not an adequate width to suppress adult dispersal into the field. The percent of infested stems started to decrease at 60 m from the field edge. There was a 70% increase in WSS where no trap crop was used and the field with a solid stem trap. However, WSS infestations have been reported throughout fields not just at the margins as in the past. Goosey (1999) found when sampling fields, later emerging females travel farther into a field to oviposit, thereby increasing the chance of survival for their larvae. Therefore, it is conceivable that in years of high WSS numbers an entire field could be infested with pressure coming from all angles of the field; this would reduce the effectiveness of a trap crop.

Insecticide. Foliar and systemic seed insecticide treatments have been tested with few positive results (Holmes and Hurtig, 1952; Wallace, 1962; Wallace and McNeal, 1966). Foliar insecticides are applied directly to the crop. Systemic seed treatments are applied to the seed prior to planting and are translocated through the developing plant (Flint and Gouveia, 2001). Insecticides tend to give inconsistent results because the majority of the WSS lifecycle is spent within the stem of the plant host and therefore beyond the effect of a contact insecticide. It is possible to use a contact insecticide on the adults. However, with adult emergence extending for four to six weeks and the non-feeding behavior of the adults, contact insecticides must be applied frequently to provide control making this approach cost prohibitive. Spraying the edges of the field where most of the mating takes place, has been tried. However,

research has found this unsuccessful; it does not protect the interior of the field (Blodgett, 1997b).

Grazing. Few studies have looked at grazing to reduce insect pests. Dowdy et al. (1992), Buntin and Bouton (1996), and Guerrerno et al. (2002) looked at grazing to manage alfalfa weevil (Coleoptera: Curculionidae). Dowdy et al. (1992) reported that cattle grazing winter alfalfa at a stocking rate of 12 to 15 animals/ha in Oklahoma reduced weevil egg numbers by 67% compared to non-grazed plots. Buntin and Bouton (1996) reported that grazing in the spring reduced alfalfa weevil numbers 60% in the first year and 45% in the second year compared to a non-grazed control. The stocking rate was not given for this study. Grazing did cause some leaf damage to the alfalfa (Buntin and Bouton, 1996). Guerrerno et al. (2002) compared lamb grazing with two forms of insecticide on alfalfa pastures infested with weevils and aphids. Higher hay leaf percentages (63.2%) were found in the pasture where lambs had grazed than in the control (57.5%), the carbofuran as Furadan®-treated plots (58.6%), or the chlorpyrifos as Lorsban®. This study was only done for one year at one location.

Research in Montana found sheep grazing reduced WSS larval counts up to 87% when compared to a no input control (Hatfield et al., 1999). However, this research was only done for one year, at one location.

## Soil Bulk Density

Soil compaction is the reduction in the volume of a given mass of soil (Canillas and Salokhe, 2001). It is commonly defined as an increase in soil bulk density. Compactablity and plasticity are a soil's capability of being molded or deformed continuously and permanently. This is more related to intrinsic soil properties such as particle size distribution and clay mineralogy than classification for soil type. Bulk density is influenced by the content of organic matter and clay content (Ball et al., 2000). The ideal crop soil contains 50% solid particles, and 50% pore space. The bulk density for a mineral soil is approximately 1.3 Mg per $m^3$ (Chancellor, 1977).

The problems associated with soil compaction are excessive soil hardness, poor crop production, irregular plant growth and wet soil due to insufficient drainage, and reduced water use efficiency (Canillas and Salokhe, 2001; Radford et al., 2001). Soil properties such as texture, organic matter, water content, and other factors such as environmental conditions and grazing intensities govern the degree to which compaction occurs (Mapfumo et al., 1999). The variation of these factors makes it difficult to compare the results of grazing impacts on bulk density among sites (Mapfumo et al., 1999). The majority of soil compaction in cropland is due to vehicular traffic (Radford et al., 2001). The first pass of a wheel causes the greatest amount of soil compaction (Alakukku, 1996). Compaction is increased when soil is wet, because of reduced soil strength (Radford et al., 2001). Soil strength refers to the soil's solid phase cohesion and adhesion, is the property of soil that causes it to resist

deformation (Brady and Weil, 1999). Residual stress decreases linearly with water content and increases linearly with compression stress (Sánchez-Girón et al., 2001). Structural degradation occurs during compaction and affects plant roots and shoot growth (Burgess et al., 2000). Grazing animals can cause structure loss by stress on soil, reducing pore space between particles. Soil compaction and soil remolding can occur in response to trampling (Proffitt et al., 1995). Winter and Unger (2001) found cattle grazing on Pullman clay, irrigated wheat fields lowered yields compared to non-grazed fields. Grazing was the only difference between sites. Increases in bulk density were restricted to the top 2.5 cm of the soil at high, medium, and low grazing intensities (Mapfumo et al., 1999). They found surface bulk densities for heavy and medium stocking rates were 22 and 11% greater respectively than that for the light grazing (Mapfumo et al. 1999). These data concur with Worrell et al. (1992) who found that grazing cattle in wheat fields at a stocking rate of 5.34 head/ha from November to January increased soil compaction compared to a non-grazed control. However, Worrell et al. (1992) reported soil compaction in the top 30 cm was positively correlated with the grazing duration, rather than the top 2.5 cm as reported by Mapfumo et al. (1999). Unlike cattle, Drewry et al. (1999) found high intensity sheep grazing in irrigated pastures had no long-term detrimental effects on soil compaction. In their study, sheep were grazed at a stocking rate of 1800 sheep per ha, in the winter on ryegrass-white clover pasture, in New Zealand. Visual observations noted loss of vegetation cover, burial of plants, and damage to roots. However, soil physical effects of compaction were not as severe as expected from the visual

appearance and were generally restricted to the 0 to 5 cm soil depth. Plastic deformation rather than compaction may have been the major process responsible for the damage in the field, as soil moisture levels were high at the time (58%).

Murphy et al. (1995a) compared cattle grazing with sheep grazing on smooth-stalked meadowgrass dominant white clover sward. Animals were allowed to graze pastures until a residual herbage mass of 1100 kilogram dry matter per ha was reached. Stocking densities were approximately 80 animal units/ha for both sheep and cattle (Murphy et al., 1995a). They found soil compaction to be 81% greater under grazing by cattle compared to sheep (Murphy et al., 1995a). Carbon dioxide evolution from soil microbial respiration was less in the cattle grazed treatments than the sheep grazed treatments, due to less microbial activity and less cycling of nutrients (Paul and Clark, 1996) in the soil where the cattle were grazed. Microbial respiration levels were inversely related to soil compaction (Murphy et al., 1995a). More vigorous plant growth was observed under sheep grazing (Murphy et al., 1995b) and was probably related to the higher levels of nutrient cycled in the sheep grazing treatment and lack of soil compaction. Higher soil nutrient levels under sheep grazing may reflect a more uniform manure and urine distribution by sheep compared to cattle (Murphy et al., 1995a). Tillage and natural processes such as freezing and thawing can alleviate compaction in surface layer (Radford et al., 2001).

## Biomass and Weeds

Because most wheat production in Montana is non-irrigated (dryland), soil moisture is extremely important. Therefore, fallow is used to capture and store soil moisture. In a fallow system a field will be left non-cropped between crops. Weed and volunteer cereal growth in the fallow areas deplete soil water and nutrients that are stored for the subsequent crop. Weed growth in fallow can reduce subsequent wheat yields by 509 to 1525 kilograms per ha (Greb, 1981). Schillinger and Young (2000) found a single Russian thistle (*Salsola iberica*) can use up to 70 liters of water in wheat fallow and can deplete water to a depth of 1.2 meters. This loss of water reduced grain yields by approximately 425 kilograms per ha (Shillinger and Young, 2000). Russian thistle biomass has been found to increase with a decrease in soil moisture (Young, 1988). Weed infestations are most severe when crop competition is reduced by poor stands, drought, inadequate fertility, and/or late growth (Shillinger and Young, 2000). Downy brome (*Bromus tectorum L.*) densities of 11 to 22 plants per $m^2$ depress winter wheat yields 30% in Nebraska (Kettler et al., 2000). Kochia has been found to have a competitive advantage over sugarbeets (Wheatherspoon and Schweizer, 1969). The earlier emergence of kochia gives it a competitive advantage over spring wheat.

Cultural practices

Tillage. Roger-Estrade et al. (2001) reported tillage operations improved soil structure, buried fertilizer, and controlled weeds. However, tillage had several drawbacks, including mechanical turnover of soil is costly, it can bring new seeds to the soil surface, it kills soil fauna, and disrupts soil nutrient cycling (Schjønnin and Rasmussen, 2000). Runoff of soil nutrients through water erosion is higher in tilled fields than non-tilled fields (Hanson et al., 2000; Planchon et al, 2000). Frequent use of the moldboard plow causes decline in soil organic carbon, decreases in soil structure and aggregation, reduces water infiltration rates, and increases soil erosion (Kettler et al., 2000). The average soil loss from tillage is 24 metric tons/ha compared to 1.8 metric tons/ha for stubble mulch (Fenster, 1997). Soon et al. (2001) found crop nitrogen uptake was greater, more turnover of microbial biomass, and $NO_3$ was higher at harvest in no till than conventional wheat tillage systems.

Burning. Burning is used to reduce biomass in wheat fields. The advantages of burning are that it is a quick way to remove residue, weeds, and some insect pests. There are conflicting reports on the effects of burning on wheat yields. Hemmat and Taki (2001) found in irrigated wheat, yields were increased in burned plots. Ammonium nitrate and bicarbonate-extractable phosphorus were increased. However, Dormaar et al. (1979) found a fallow rotation system reduced wheat yields following stubble burning. They reported a reduction in organic carbon, polysaccharides, $NH_4$-

N, $NO_3$-N, and available phosphorus. These differences may be due to soil type and/or irrigated versus dryland cropping.

Du Preez et al. (2001), found no evidence to suggest any difference between burning and conventional tillage on the uptake of K, P, or Zn in a semiarid Plinthosol soil. Dormaar et al. (1979) suggested that occasional burning might not have lasting harmful effects on yield. Under dryland cropping systems other straw management systems than burning should be implemented according to Dormaar et al., 1979. Furthermore, more fertilizer may be required when fields are burned (Dormaar et al., 1979).

Herbicide. Since 1940, herbicides have been used to supplement weed control obtained with tillage and seedbed preparation prior to planting (Wiese, 1985). Montana wheat producers use approximately 2 million kilograms of active herbicide ingredient annually on summer fallow ground (Johnson et al., 1997; Montana Agricultural Statistics, 2000). This chemical-fallow system replaces tillage with herbicides for weed control in the fallow period. In the Northern Great Plains, approximately 6 million ha of farmland are rotated into fallow annually with herbicides used for weed control on the majority of these acres (Stewart, 1988).

Soil moisture conservation is a major concern of wheat producers in Montana and the Northern Great Plains (Wiese, 1985). Managing weeds with herbicides leaves stubble standing to trap snow and increase soil moisture. Brown (1977) developed a soil water and precipitation guide for Montana. This guide indicates that successful

annual cropping of spring wheat requires 100 to 250 mm of water from stored soil water and/or rainfall sources to grow a satisfactory crop (Brown, 1977).

Grazing. Sheep have been used on rangeland to manage tansy ragwort (*Senecio jacobaea*), leafy spurge (*Euphorbia esula* L.), and spotted knapweed (*Centaurea maculosa* Lam.) (Sharrow and Mosher, 1982; Olson and Wallander, 1998; Olson et al., 1997, respectively). Sharrow and Mosher (1982) found sheep to be more effective at removing tansy ragwart than cattle (43 plants were defoliated compared to 100 plants on the sheep and cattle combined grazed plots). Utilization of the tansy ragwart was 20% for the cattle and 80% for the sheep (Sharrow and Mosher, 1982).

Olson and Wallander (1998) reported grazing leafy spurge infested pastures with five yearling ewes per 1.7 ha increased the density of Idaho fescue. They reported the sheep tended to prefer leafy spurge more than some perennial grasses. The sheep grazing reduced the leafy spurge seed in the seedbank compared to non-grazed (Olson and Wallander, 1998). Seed densities in the summers of 1993 and 1995 were significantly higher averaging over 800 seedlings per $m^2$ in non-grazed plots versus 534 seedlings per $m^2$ in grazed plots (Olson and Wallander, 1998).

Sheep have been reported to reduce densities of spotted knapweed (Olson et al., 1997). More viable spotted knapweed seeds were recovered from non-grazed areas than grazed areas (49 per $m^2$ versus 12 per $m^2$). Consequently, the frequency of Kentucky bluegrass increased 20% in grazed areas compared to non-grazed areas (Olson et al. 1997).

## Stubble Grazing

Sheep and goats have been used in developing countries to graze stubble for centuries (Owen and Kategile, 1984). Many grain producers in Britain used sheep grazing to add fertility to the soil (Owen and Kategile, 1984). Straw is a major crop residue resource (Tan et al., 1995). Straw and crop litter comprise more than 50% of the total dry matter production of the crop and a high proportion of this straw may be available for grazing (Mulholland et al., 1976). If one-half of the available cereal grain aftermath is left in the field to prevent soil erosion and catch snow to increase soil moisture, and the remaining residue is fed to beef cows as a winter feed, 17.5 million brood cows could be supplemented for five months from the residue in the Pacific Northwest alone (Males, 1987). Corn residue is an economically important beef cattle feed in the late fall and winter for the Midwest (Klopfenstein et al., 1987). However, grazing as a wheat fallow management tool has not been looked at in detail.

### Nutritive Value

Straw stubble is characterized by low levels of nitrogen and available carbohydrates, as well as high cell wall content, and poor digestibility (Brand et al., 1999). Wheat stubble may not meet the nutritive requirements for producing sheep (Brand et al., 1999). Supplement is typically needed to meet the requirements of producing sheep especially lactating and pregnant ewes (Brand et al., 1999). In a review of literature on grazing cereal crop residue, Males (1987) found that either chemically treated straw or supplementation could maximize the utilization of cereal

crop residue as a feed for beef cows. Mulholland et al. (1976) evaluated cereal stubble for sheep production. They suggested cereal stubble, that contained some green material, offered an alternative grazing resource for wethers and dry ewes at a stocking rate of 10.5 animals per acre for 11 wks. The sheep in the study were 10 to 16 months old and weighed between 23 to 36 kilograms. Sheep grazing at a stocking rate of 15 to 30 sheep/ha on weedy stubble gained 4.5 kilograms during the first 40 d. Lambs supplemented with urea performed similarly to non-supplemented lambs. In a similar study, Thomas et al. (1990) found that when sheep grazed weedy barley stubble in Montana at a stocking rate of 10 sheep/ha, the stubble was capable of supporting economic lamb production. They compared non-supplemented lambs with lambs that were supplemented in year one with soybean meal, blood meal plus corn gluten meal; in year two, lambs were supplemented with barley grain, or soybean meal plus barley grain. Gains were greater in both years for lambs supplemented with the soybean meal but there were no differences between the lambs that were not supplemented and those supplemented with blood meal plus corn gluten meal or barley grain.

Brand et al. (1999) looked at differences in stocking rate and production status of ewes grazing wheat stubble. In this study they used 12 producing ewes and 20 dry ewes. They were randomly placed into groups consisting of 10 dry and six producing ewes each. The stocking rates were one and two ewes per ha for five consecutive months. They found sheep grazing at higher stocking rates had lower crude protein intakes. The results indicate that although the minimum requirements for microbial

protein synthesis and digestibility exceeded the optimal levels for maximum intake of low quality forage were not reached (Brand et al., 1999). Brand et al. (1999) concluded there was a need for supplementation of ewes grazing wheat stubble during late pregnancy and lactation.

Differences in Digestibility of Stubble

Tan et al. (1995) evaluated three varieties of wheat straw for differences in nutritive characteristics resulting from variations in the proportions of morphological fractions and chemical composition of the straw as well as the genetic, environment, and management factors. They found higher neutral detergent fiber and lignin contents but lower crude protein and neutral detergent soluble contents for the whole wheat plant during maturation. Feed nutritive value of leaf blades is highest, then second highest was leaf sheath, the lowest was the stem, which constitutes more than 50% of the whole plant. Soil type had little effect on the nutrient value of the plants. They found that nutritive quality did differ among the three genotypes. Ohlde et al. (1992) found similar results when comparing eight different straw species, barley (spring and winter), wheat (spring and winter), durum, rye, triticale, and oat. They found the ligninfied, thick cell walls of some straws were markedly colonized and eroded by microorganisms and, as a result, contributed substantially to the total in vitro digestibility of cell walls. Of these winter wheat and durum wheat had the highest cell wall digestibility (Ohlde et al., 1992). Goto et al. (1991) evaluated morphological and anatomical variations among 'Golden Promise', 'Klaxon', and 'Doublet' barley cultivars. They found newer wheat varieties had lower digestible NDF than older,

taller varieties. This could be due to breeding these new varieties to put more energy into the kernels for higher yield and less into the plant structure.

## Environmental Concerns with Management Practices

### Tillage

Tillage is utilized to fulfill three requirements: 1) improve soil tilth, 2) combat weeds, and 3) incorporate plant residue and organic matter (Schjønning et al., 2000). However, mechanical turnover of the top 20 to 25 cm layer of soil is a costly process requiring energy inputs. It brings new weed seeds to the top soil layer for germination, and it kills soil fauna active in the turnover of organic matter (Schjønning and Rasmussen, 2000). Investigations have reported a significant densification of the soil layer just below soil plowing depth (Francis et al., 1987). Continued plowing of many soils with tractors of ever-increasing weight and power has created critical conditions for soil processes such as air exchange (Schjønning, 1989) and water movement (Comia et al., 1994). Kosmas et al. (2001) looked at the effects of tillage displaced soil on soil properties and wheat biomass. They found displacement of topsoil by moldboard plow reduced the effective soil depth and water holding capacity. However, the water holding capacity prior to the study was not given.

### Burning

According to the EPA (2003) the major air pollutants of agricultural burning is a complex mixture of carbons, tars, liquids, and different gasses. Open combustion sources produce particles of widely ranging sizes. The major pollutants in wildland

and agricultural burning are particulates, carbon monoxide, and volatile organics (EPA, 2003). Nitrogen oxides are emitted at rates of 1 to 4 g/kg burned, depending on combustion temperatures (EPA, 2003).

Field burning of crop residue is not considered a net source of carbon dioxide ($CO_2$) because the carbon released to the atmosphere as $CO_2$ during burning is assumed to be reabsorbed in the next growing season (EPA, 2003). However, burning crop residue is a net source of methane ($CH_4$), nitrous oxide ($N_2O$), carbon monoxide (CO), and nitrogen oxides ($NO_x$), which are released during combustion (EPA, 2003).

Health consequences from burning agricultural residue are not fully understood (Long et al., 1998). Many components of agricultural smoke are known to cause health problems under certain conditions, such as the health of the individuals and amount of smoke and duration of exposure (Committee of the Environmental and Occupational Health Assembly, 1996). However, due to the relatively short exposure, smoke may be more of a nuisance than a real health hazard (Bates, 1992). In a study by Long et al. (1998) individuals were studied in Winnipeg, Canada after an episode of elevated levels of particulate matter, carbon monoxide, nitrogen dioxide, and volatile organic compounds due to smoke from adjacent fields where farmers were burning agricultural residue. During this time the total suspended particulate matter (TSP) reached a peak value of more than 200 $\mu g/m^3$. Total suspended particulate matter is associated with the prevalence of chronic bronchitis, wheezing, and hospital admissions for respiratory disease (Schwartz, 1993). The risk of chronic bronchitis increases linearly when TSP increases from 60 to 100 $\mu g/m^3$ (Long et al., 1998). Long

et al. (1998) found that individuals with chronic phlegm production, dyspnea, wheezing, or asthma were more susceptible to exposure to air pollution than people without symptoms. Of these who were susceptible to pollutants, 37% were women and 23% were men.

Grazing

There is evidence that suggests that overgrazing and other human disturbances can be causes of scarcity of perennial grasses in grasslands (Joffere et al., 1987; Rossiter 1966). Overgrazing results in modifications in the ecosystems of arid and semi-arid areas (Villamil et al., 2001). If the damage to plants and soil is irreversible the sustainability of these habitats is jeopardized (Milton et al., 1997).

Due to high erosion potential in Montana (NRCS, 1997) management systems that maintain residue cover are important. The NRCS recommends plant cover to be 25 to 30% on a clay loam soil to reduce erosion (Lenssen, Personal Communication, 2003). Most producers have conservation plans with NRCS. The guidelines for these contracts are in the Federal Register: April 2, 1998 (Volume 63, Number 63) proposed rules, pages 16142-16148. Briefly, in accordance with the Food Security Act of 1985 the Commodity Credit Corporation (CCC) established a pilot program for producers of wheat, feed grains, upland cotton, and rice. Producers accepted into the Conservative Farm Option (CFO) entered into 10-year contracts, which may be extended an additional 5 years. The purpose of the program is 1) conserve soil, water, and related resources, 2) water quality protection or improvement, 3) wetland restoration, protection, and creation, 4) wildlife habitat development, and 5) other similar

purposes. In order to enroll in the program producers had to prepare a conservation farm plan, which becomes part of the CFO contract. The plan describes all conservation practices to be implemented and maintained on acreage subject to the contract. All management practices must comply with the plan including grazing.

## Summary

Wheat production is the largest agricultural crop industry in Montana. Wheat stem sawfly is the most damaging insect pest in Montana wheat production (Blodgett et al. 1997a and b). Management of WSS is difficult due to its biology (Anslie, 1920). The majority of the WSS life cycle is spent within the stem of its host (Anslie, 1920). It overwinters within the stub in fallow beneath the soil surface. This insulates larvae from environmental effects and desiccation (Anslie, 1920). Disruption of the habitat can lead to mortality.

Grazing has been found to reduce weeds (Olson and Wallander, 1997) and increase both the mortality of WSS (Hatfield et al. 1999) and alfalfa weevil (Guerrero et al., 2002). Sheep grazing does not increase soil bulk density (Murphy et al. 1995b).

The null hypotheses for this project was: 1) grazing would not disrupt the overwintering habitat of WSS, therefore not increase WSS mortality, 2) grazing sheep would not increase soil bulk density (compaction), and 3) grazing would not reduce plant biomass and weeds. Therefore, the objectives of our study were to compare burning, grazing, tilling, trampling and clipping wheat stubble fields in a multi-farm

study on: 1) overwintering WSS larval populations, 3) changes in soil bulk density, and 2) total plant biomass including wheat stubble, volunteer wheat and weeds.

# MATERIALS AND METHODS

Field trials were conducted at eight sites on four farms located in Montana with high (over 50% of stems cut) WSS infestations to evaluate the effects of various management strategies on WSS larval mortality. The experimental design was a complete randomized block design. All treatments were represented within each site and replicated four times (four blocks/site). Individual plot size was 9 x 12 m. Beginning treatment samples were taken October 2000 and September 2001; ending treatment sampling were collected May 2000 and May 2001, in the first and second years, respectively.

## Experiments and Treatments

### Graze Experiment.

The treatments were a no input control **(GC)**, fall tilled **(GT)**, fall grazed **(GF)**, spring grazed **(GS)**, and fall and spring grazed **(GFS**; Table 1). Five mature western white-faced ewes were randomly assigned to each grazed plot. Sheep were kept in plots for 24 hours 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 GF and GS stocking rate was 400 sheep d/ha (2.1 aum). Stocking rate for GFS was 800 sheep d/ha (4.2 aum). Tillage was done with a three-point small plot chisel plow. Plots were tilled once to a depth of approximately 20 cm.

Table 1. Studies, treatments and their respective abbreviations with numbers of sites, blocks and plots.

| Experiment | Treatment | Abbreviation | Comment |
|---|---|---|---|
| Grazed | | | |
| | Control[b] | GC | 8 sites, 4 blocks, 32 plots |
| | Tillage[c] | GT | 8 sites, 4 blocks, 32 plots |
| | Fall Graze[a] | GF | 8 sites, 4 blocks, 32 plots |
| | Spring Graze[a] | GS | 8 sites, 4 blocks, 32 plots |
| | Fall+Spring Graze[a] | GFS | 8 sites, 4 blocks, 32 plots |
| Burned | | | |
| | Burn[d] | BB | 6 sites, 4 blocks, 24 plots |
| | Control[b] | BC | 6 sites, 4 blocks, 24 plots (Subset of GC) |
| | Tillage[c] | BT | 6 sites, 4 blocks, 24 plots (Subset of GT) |
| | Fall Graze[a] | BF | 6 sites, 4 blocks, 24 plots (Subset of GF) |
| Trampled | | | |
| | Control[b] | TC | 2 sites, 4 blocks, 8 plots (Subset of GC) |
| | Fall Trample[e] | TF | 2 sites, 4 blocks, 8 plots |
| | Spring Trample[e] | TS | 2 sites, 4 blocks, 8 plots |
| | Fall+Spring Trample[e] | TFS | 2 sites, 4 blocks, 8 plots |
| | Clip[f] | TCP | 2 sites, 4 blocks, 8 plots |

[a] Sheep grazed 111m² plots for 24h (48h for Fall+Spring); Fall and Spring grazed at 400 sheep d/ha, Fall+Spring grazed at 800 sheep d/ha

[b] No input control

[c] Shallow tillage (20 cm) was conducted within 72h of fall grazing

[d] Burning was conducted within 72h of fall grazing

[e] All sheep were muzzled while occupying a 111m² plot for 24 hr (Fall+Spring 48h); Fall and Spring = 400 sheep d/ha, Fall+Spring = 800 sheep d/ha

[f] Stubble clipped between 2 – 7cm; conducted within 72h of fall trampling

Burn Experiment.

Burned control **(BC),** fall grazed **(BF)**, and fall tilled **(BT)** were subsets of GC, GF, and GT, respectively (Table 1). These treatments along with the burned treatment **(BB)** was imposed at six of the eight sites. Burning was done with a propane brush burner.

Trample Experiment.

The trample control **(TC)** treatment was a subset of GC (Table 1). The other treatments were fall clipped **(TCP)**, fall trampled **(TF)**, spring trampled **(TS)**, and fall and spring combined trampled **(TFS)**. Sheep were muzzled to prevent grazing within the plot. The stocking rate for the trample treatments was the same as for the grazed treatments. Stubble was clipped between two to seven cm within 72 h of TF.

## Experiment Sites

Sites 1 and 2 were located in Stillwater county, south central Montana (Figure 1). These sites had been seeded to winter wheat. Sites 3 through 8 were located in Toole and Pondera counties, north central Montana (Figure 1). They were also seeded to winter wheat. All sites were established on grain stubble fields resulting from 2000 (sites 1 through 4) and 2001 (sites 5 through 8) crops (Table 2). Precipitation was lower than average and with more frost-free days for both years at all sites (NASS, 2003; Table 2). The soils at all sites are clay loams (NRCS, 1980; Table 3).

Due to drought in spring 2001, sheep were supplemented with a lamb creep and finisher ration from Land O' Lakes Feed (St. Paul, MN). It contained a minimum

Table 2. Research sites, locations, precipitation, and frost-free days during 2000 through 2003 in Montana.

| | Location | | | | Precipitation [a] | | Frost-Free Days[a] | |
|---|---|---|---|---|---|---|---|---|
| Site | Latitude | Longitude | County | Study Year | During Study | Normal 2/ | During Study | Normal 3/ |
| 1 | 46° 02' 44" | 109° 13' 41" | Stillwater | 2000 - 2001 | 13.08 | 14.74 | 133 | 125 |
| 2 | 46° 02' 58" | 109° 12' 25" | Stillwater | 2000 - 2001 | 13.08 | 14.74 | 133 | 125 |
| 3 | 48° 13' 11" | 111° 42' 21" | Pondera | 2000 - 2001 | 8.11 | 11.88 | 118 | 100 |
| 4 | 48° 13' 03" | 111° 39' 29" | Pondera | 2000 - 2001 | 8.11 | 11.88 | 118 | 100 |
| 5 | 48° 13' 01" | 111° 45' 03" | Pondera | 2001 - 2002 | 7.11 | 8.99 | 127 | 90 |
| 6 | 48° 13' 06" | 111° 45' 28" | Pondera | 2001 - 2002 | 7.11 | 8.99 | 127 | 90 |
| 7 | 48° 15' 38" | 111° 38' 15" | Toole | 2001 - 2002 | 7.11 | 8.99 | 127 | 90 |
| 8 | 48° 15' 22 | 111° 39' 42" | Toole | 2001 - 2002 | 7.11 | 8.99 | 127 | 90 |

[a] Values taken from Montana Agricultural Statistics (NASS, 2003; NASS, 2002) for appropriate year

Figure 1. Research site locations. (Blodgett et al., 1997b)

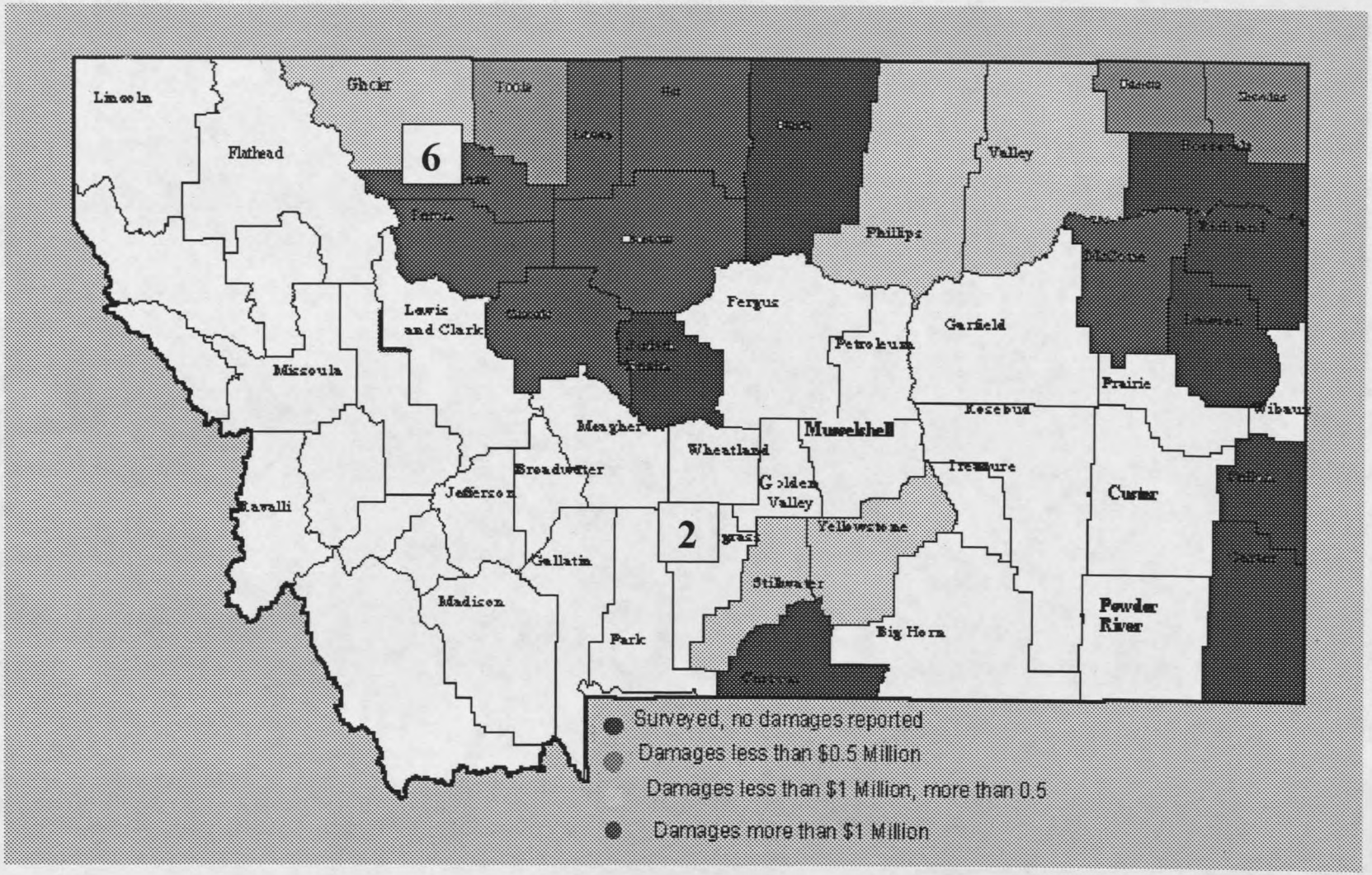


Table 3. Soil names, classifications, slope, and permeability

| Site | Soil Classification | Family or Higher Taxonomic Classification | Slope | Permeability |
|---|---|---|---|---|
| 1[a] | Yamac Loam | Fine-loamy, mixed Borollic Camborthids | 2-4 % | Moderate |
| 2[a] | Yamac Loam | Fine-loamy, mixed Borollic Camborthids | 2-8% | Moderate |
| 3 | Scobey – Kevin Clay Loam | Aridic Argiborolls, fine, montmorillonitic | 0-4% | Moderate |
| 4 | Telstad – Joplin Loam | Aridic Argiborolls, fine-loamy, mixed | 0-4% | Moderate |
| 5 | Scobey – Kevin Clay Loam | Aridic Argiborolls, fine, montmorillonitic | 4-8% | Moderate |
| 6 | Scobey – Kevin Clay Loam | Aridic Argiborolls, fine, montmorillonitic | 4-8% | Moderate |
| 7 | Telstad – Joplin Loam | Aridic Argiborolls, fine-loamy, mixed | 0-4% | Moderate |
| 8 | Evanston Clay Loam | Aridic Argiborolls, fine-loamy,mixed | 0-4% | Moderate |

[a] Data taken from Soil Survey of Stillwater County, Montana, 1980

of 15% crude protein, 2.25% crude fat, 0.2% phosphorus, 0.3 ppm selenium, 18 – 19% crude fiber, 0.5 – 1.1% calcium, and 0.9 – 1.1% salt.

## Wheat Stem Sawfly

Plots were sampled to determine WSS larval counts prior to any treatment imposition in September and October (beginning) and following overwintering and spring completion of the treatments in May (ending). 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 a laboratory where WSS cut stems were identified and dissected to determine if they contained live WSS larvae. The response variables were beginning and ending live larval numbers, change in live larvae between beginning and ending and percent mortality of overwintering larvae in each plot. Calculations for percent mortality were made from the beginning and ending data from each plot and were calculated as percent mortality = [(beginning samples – ending samples)/beginning samples] x 100.

## Soil Bulk Density

Treatment effect on soil bulk density was determined using three compaction core samples per plot. A sample consisted of the volume of soil within the 91 $cm^3$ compaction core sampler (AMS, American Falls, ID). Samples were labeled and returned to a lab at Montana State University, dried at 105° C for 48 h and weighed.

The response variables were beginning and ending soil bulk density, change in soil bulk density between beginning and ending, and percent change in bulk density which was calculated as [(ending mean – beginning mean)/beginning mean] X 100.

## Biomass and Weeds

### Plant Biomass.

Three samples were taken per plot with a 0.1 $m^2$ ring. A sample consisted of all live and dead vegetative matter within a 0.1 $m^2$ ring. All samples were labeled and returned to a laboratory where they were dried at 50° C for 48 h and weighed. The response variables were beginning and ending plant biomass, change in plant biomass between beginning and ending, percent change in plant biomass calculated from the beginning and ending treatment, and percent biomass remaining calculated as (ending mean/beginning mean) x 100.

### Weed Frequency.

Weed frequency was determined only in the first year of the trial due to a lack of weeds in the second year because of drought. Three samples were taken per plot. All weeds within a 0.10 $m^2$ ring were counted and plant frequency was determined by the number of plants per 0.10 $m^2$ ring. Change in plant frequency was calculated from change between beginning and ending treatments and calculated as ending treatment mean – beginning treatment mean. The *response variables were beginning and* ending weed frequency and change in percent weeds remaining, which was calculated as (ending treatment mean/ beginning treatment mean) x 100.

## Statistical Analysis

A randomized complete block design with four blocks was imposed at each site. The study consisting of three experiments (graze, burn, and trample) was conducted over a two year period at four locations per year. Rather than location, year, and location by year, location and year were combined into one term defined as site. The model included effects of site, treatment, and site by treatment interaction. Least squared means were calculated using the GLM procedure of SAS (SAS Institute, Cary, NC) to make comparisons among treatments within studies. Treatment comparisons were considered significant when $P$ was $\leq 0.10$.

# RESULTS AND DISCUSSION

## Wheat Stem Sawfly

### Grazing Versus Control and Tillage Experiment

Beginning WSS Larval Numbers. The site by treatment interaction was significant ($P<0.01$;Table 4; Appendix Table A). Therefore, results are presented as the simple effects of treatment within location.

Ending WSS Larval Numbers. The site by treatment interaction ($P<0.01$) was significant for the number of WSS larvae at the end of the experiment period (Table 4; Appendix Table A). Therefore, results are presented as the simple effects of treatment within location.

At the end of the experiment, GC and GT did not differ ($P=0.14$) in WSS live larvae counts at seven sites out of eight sites (Table 4; Appendix Table A). At one site, ending live WSS numbers were greater ($P=0.04$) for GC than GT.

Ending live larval WSS numbers were greater ($P<0.04$) for GC at two, three, and four sites than GF, GS, and GFS, respectively. There were no differences ($P>0.14$) at the end of the experiment between GC and GF, GS, or GFS at the remaining sites (Table 4; Appendix Table A).

When comparing GT to GF, GS, or GFS, GT had a greater ($P<0.06$) ending live larvae numbers at one, three, and three sites than GF, GS, or GFS, respectively. At the end of the experiment, there were no other differences ($P>0.14$) between GT

Table 4. Interaction[a] of site by treatment for beginning and ending wheat stem sawfly counts per 0.46 m of row in control **(GC)**[b], tilled **(GT)**[c] fall **(GF)**, spring **(GS)**, and fall+spring **(GFS)** grazed[d] plots at 8 sites[e] in Montana, taken October 2000, May 2001, September 2001, and May 2002.

| | | | Grazed | | | |
|---|---|---|---|---|---|---|
| Site | Control | Tilled | Fall | Spring | Fall+Spring | SE |
| Beginning treatment | | | | | | |
| 1 | 11.8 | 10.1 | 12.0 | 9.7 | 12.2 | 1.11 |
| 2 | $13.3^{xy}$ | $14.5^{y}$ | $14.0^{y}$ | $9.8^{x}$ | $15.7^{y}$ | 1.48 |
| 3 | $36.5^{xy}$ | $38.9^{y}$ | $42.5^{y}$ | $26.3^{x}$ | $35.8^{xy}$ | 4.38 |
| 4 | $39.5^{y}$ | $41.3^{y}$ | $36.3^{y}$ | $14.0^{x}$ | $37.0^{y}$ | 3.15 |
| 5 | $5.8^{xy}$ | $5.5^{x}$ | $8.3^{xy}$ | $6.6^{xy}$ | $8.8^{y}$ | 1.63 |
| 6 | 6.6 | 5.8 | 7.6 | 5.8 | 7.4 | 1.35 |
| 7 | 2.0 | 1.8 | 4.3 | 3.6 | 2.4 | 1.04 |
| 8 | 8.2 | 8.3 | 9.1 | 9.8 | 10.0 | 1.49 |
| Ending treatment | | | | | | |
| 1 | $5.1^{x}$ | $2.2^{y}$ | $2.3^{y}$ | $1.3^{y}$ | $1.0^{y}$ | 0.88 |
| 2 | $6.5^{yz}$ | $7.2^{z}$ | $3.7^{xz}$ | $2.8^{xy}$ | $1.4^{x}$ | 1.59 |
| 3 | $26.4^{x}$ | $22.9^{x}$ | $22.2^{x}$ | $9.1^{y}$ | $11.8^{y}$ | 3.01 |
| 4 | $28.0^{y}$ | $27.2^{y}$ | $16.8^{z}$ | $8.9^{x}$ | $12.4^{xz}$ | 2.57 |
| 5 | 1.8 | 2.5 | 2.7 | 2.4 | 2.1 | 1.42 |
| 6 | 3.1 | 3.2 | 2.9 | 2.0 | 2.3 | 0.74 |
| 7 | 1.1 | 1.3 | 1.1 | 1.9 | 1.4 | 0.65 |
| 8 | 5.1 | 5.5 | 3.1 | 4.7 | 2.0 | 0.18 |

[a] Site x treatment interaction was detected ($P<0.01$)

[b] No input control

[c] Shallow tillage (20 cm) was conducted within 72h of fall grazing.

[d] Sheep grazed 111m² plots for 24h (48h for Fall+Spring); Fall and Spring grazed at 400 sheep d/ha, Fall+Spring grazed at 800 sheep d/ha

[e] Sites located in Toole, Pondera, and Stillwater counties

[x,y,z] Means within a row lacking a common superscript differ $P<0.10$

and any of the grazing treatments (Table 4; Appendix Table A). At the end of the experiment, grazing treatments did not differ ($P>0.18$) at six, seven and eight experiment sites between GF versus GS, GF versus GFS, and GS versus GFS, respectively. At two sites at the end of the experiment, GF had greater ($P<0.05$) ending live larvae numbers than GS. At one site, GS had greater ($P=0.01$) ending live larvae than GFS (Table 4; Appendix Table A).

Change in WSS Larval Numbers. Site by treatment interaction was not significant ($P=0.37$), for change in the number of WSS live larvae. Therefore, main effects of treatment across sites are presented (Table 5).

When comparing GC to GT or GC to GS for change in WSS larval numbers no differences ($P=0.41$; $P=0.54$, respectively) were detected from the beginning to the end of the experiment (Table 5). There was a greater reduction ($P<0.01$) of larval numbers in GF and GFS than GC (Table 5).

There was no difference ($P=0.82$) in change in WSS larval numbers between GT and GS. Fall grazed and GFS had greater reductions ($P<0.02$) in of larval numbers than GT (Table 5).

Change in larval numbers did not differ ($P=0.11$) between GF and GFS. Spring grazed had less reduction ($P<0.01$) of larvae numbers than both GF and GFS (Table 5).

Percent WSS Mortality. The site by treatment interaction was not significant ($P=0.99$; Table 5). Therefore, main effects of treatment across sites are presented.

Table 5. Change[a] and percent mortality[a] of wheat stem sawfly live larvae counts per 0.46m of row in control **(GT)**[b], Tilled **(GT)**,[c] fall **(GF)**, spring **(GS)**, and fall+spring **(GFS)** grazed[d] plots at 8 combined sites[e] in Montana, taken October 2000, May 2001, September 2001, and May 2002.

| | | | Grazed | | | |
|---|---|---|---|---|---|---|
| | Control | Tilled | Fall | Spring | Fall+Spring | SE |
| Change, live larvae | -5.7$^{x}$ | -6.8$^{x}$ | -9.3$^{y}$ | -6.5$^{x}$ | -12.0$^{y}$ | 0.98 |
| Mortality, % | 43.5$^{x}$ | 46.8$^{x}$ | 62.9$^{y}$ | 61.0$^{y}$ | 74.2$^{z}$ | 4.07 |

[a] No site x treatment interaction was detected ($P>0.80$)

[b] No input control

[c] Shallow tillage (20 cm) was conducted within 72h of fall grazing

[d] Sheep grazed 111m² plots for 24h (48h for Fall+Spring); Fall and Spring grazed at 400 sheep d/ha, Fall+Spring grazed at 800 sheep d/ha

[e] Sites located in Toole, Pondera, and Stillwater counties

[x,y,z] Means within a row lacking a common superscript differ $P<0.10$

Differences were not significant ($P$=0.55) between GC and GT for percent WSS mortality (Table 5). Control had a lower ($P$<0.01) percent mortality than GF, GS, and FS (Table 5).

All grazing treatments had a higher ($P$>0.01) percent mortality than GT. The GFS treatment had a higher ($P$<0.04) percent mortality than either GF or GS. No difference ($P$=0.72) was detected in percent mortality between GF and GS (Table 5).

Discussion. Hatfield et al. (1999) found WSS mortalities of up to 87% when sheep grazed both fall and spring. Our results were similar with the percent mortalities being 63%, 61%, and 74% for GF, GS and GFS, respectively (Table 5). Hoof action does not disrupt the soil in the same way as tillage. Grazing the stubble may disrupt the stubs where the larvae are overwintering as well as loosen the soil around the roots below the surface. Tillage does not breakdown soil from crowns which keeps the larvae protected, However, the hoof action churns the soil, loosening it just at the soil surface. This allows for more air circulation and moisture to penetrate down to the roots/crowns region of the wheat plant, possibly increasing freezing or desiccation of the larvae within the stem. Grazing the stubble breaks the stubs and disturbs the frass plug the larvae has deposited in the stub to protect itself from overwintering conditions and the desiccation of the larvae within the stub.

Church (1955) found when researching the effects of moisture and temperature on developing WSS larvae, those larvae collected in the early spring had advanced far enough and had absorbed enough water to be practically unaffected by moisture which would cause desiccation. However, it was found that larvae collected in the fall, when

subjected to moisture during pretreatment, then subjected to dryness for 50 days had mortality rates of 100%, for 20 days 86% mortality, and for 5 days 79% mortality (Church, 1955). This may explain some of the differences in our mortality rates in the fall grazed plots, stubs were broken or disrupted, both at a time when the larvae are most susceptible to desiccation and they were still in relatively moist environment. They were then exposed to both cold temperatures of below 0° C as well as dry winter conditions (Table 2).

Goosey (1999) speculated that in order for tillage to be a method of WSS control the soil needed to be removed from around the root area to increase WSS desiccation due to freezing and drying. In a trial using standard farm tillage, only 35% of the plant crowns were soil free following tillage (Goosey, 1999). We used standard shallow tillage of approximately 20 cm, and made no effort to remove soil from crowns. Our results show WSS mortality was not significantly different ($P$=0.55) between GC (43%) and GT (47%), nor did change in WSS live larvae differ ($P$=0.41) between GT and GC (Table 5). More live larvae were found in the GS plots than GF or GFS. However, this difference was not reflected in the percent mortality. These results are consistent with Goosey (1999), Farstad et al. (1945), and Holmes (1954a) who emphasized that exposure of stems is needed to increase mortality in WSS. Holmes (1954a) found that to reach 96% WSS mortality, spring wheat stubs must be exposed to environmental conditions between May 25 and June 4. At this time the larvae within the stem are between diapause and pupation and are more susceptible to desiccation. The average temperature and moisture at the time of this research was not

collected on site, which could partially explain the higher mortalities in this work then we have seen in our spring treatments. Due to the synchrony of adult WSS to crop growth stage, WSS has adapted to winter wheat whereas this experiment was done in spring wheat (Holmes, 1975; Goosey, 1999). The larvae Church (1955) collected in the early spring had advanced far enough and had absorbed enough water to be practically unaffected by moisture levels that would cause desiccation. This may explain the reduced mortalities we saw in the GS plots. The larvae may have been too far advanced to be affected by environmental conditions. This may be similar to what Holmes (1954a) found when WSS larvae were collected from spring wheat after June 4. Church (1955) reported the highest WSS mortality rates were in the fall.

Our highest percent mortalities (74%) were found in the GFS plots. These plots were grazed in the fall and then regrazed in the spring, doubling the stocking rate and stress on the larvae within the stems. According to our results there was no difference ($P$=0.72) between GF and GS in WSS mortality (Table 5). All grazing treatments increase mortality above GC and GT treatments.

Fall Burned Versus Control, Fall Grazed, and Tilled Experiment

Beginning WSS Larval Numbers. The site by treatment interaction was not significant ($P$=0.97) for the beginning WSS live larval numbers (Table 6). Therefore, main effect of treatment across site is presented.

Table 6. Beginning treatment[a], ending treatment[a], change[a] and percent mortality[a] of wheat stem sawfly live larvae counts per 0.46m of row in control **(BC)**[b], tilled **(BT)**[c], burned **(BB)**[d] and fall grazed **(BF)**[d] plots at 8 combined sites[e] in Montana, taken October 2000, May 2001, September 2001, and May 2002.

| | Control | Tilled | Burned | Fall Grazed | SE |
|---|---|---|---|---|---|
| Beginning treatment | 16.5 | 17.0 | 16.1 | 18.0 | 1.12 |
| Ending treatment | $11.2^{y}$ | $10.4^{y}$ | $10.0^{xy}$ | $8.1^{x}$ | 0.92 |
| Change, live larvae | $-5.3^{x}$ | $-6.6^{x}$ | $-6.1^{x}$ | $-10.0^{y}$ | 1.15 |
| Mortality, % | $41.5^{x}$ | $40.0^{x}$ | $45.7^{x}$ | $58.8^{y}$ | 4.86 |

[a] No site x treatment interaction was detected ($P>0.22$)
[b] No input control
[c] Shallow tillage (20 cm) was conducted within 72h of fall grazing
[d] Burning was conducted within 72h of fall grazing[e] Sheep grazed 111m² plots for 24h
[e] Sites located in Toole, Pondera, and Stillwater counties
[x,y] Means within a row lacking a common superscript differ $P<0.10$

Ending WSS Larval Numbers. The site by treatment interaction was not significant ($P$=0.23) for ending WSS live larval numbers (Table 6). Therefore, main effect of treatment across sites is presented. Live larval numbers at the end of the experiment did not differ ($P$=0.34) between BC and BB (Table 6). There was no difference ($P$>0.12) between BB and BT or BB and BF (Table 6).

Change in WSS Larval Numbers. The site by treatment interaction was not significant ($P$=0.95) for change in live WSS larval numbers (Table 6). Therefore, main effect of treatment across sites is presented.

Change in larvae number did not differ ($P$=0.65; $P$=0.75, respectively) between BC and BB or BB and BT treatments (Table 6). Fall grazed had greater reduction ($P$=0.01) in WSS larvae numbers over the course of the experiment than BB (Table 6).

Percent WSS Mortality. The site by treatment interaction was not significant ($P$>0.94; Table 6) for percent WSS mortality. Therefore, main effect of treatment across sites is presented.

Percent mortality did not differ ($P$=0.53) between BC and BB or between BB and BT ($P$=0.39; Table 6). Fall grazed had a higher ($P$=0.05) percent mortality than BB (Table 6).

Discussion Burning does not disrupt the soil surface, which may be key in allowing for overwintering desiccation. The soil is not heated to temperatures adequate to kill larvae below the soil surface (Salt, 1947; Church, 1954). Our results

agree with those of Salt (1946 and 1947) and Church (1955), who found WSS larvae can withstand high temperatures for long length of time without desiccating.

Trample Versus Control and Clip Experiment.

Beginning WSS Larval Numbers. No site by treatment interaction ($P$>0.90) was detected for beginning WSS live larval numbers (Table 7). Therefore, main effect of treatment across site is presented.

Ending WSS Larval Numbers. A site by treatment interaction was detected ($P$=0.02) for ending live larval numbers. Therefore, results are presented as the simple effects of treatment within location (Table 8; Appendix Table B).

Ending WSS live larval numbers did not differ ($P$>0.77) between TC and TCP. Control plots had more ($P$<0.06) WSS live larvae at the end of the experiment than TF or TFS at both sites. Control had a greater ($P$=0.05) amount of WSS live larvae than TS at site 4, but did not differ at site 8 (Table 8; Appendix Table B).

The TCP treatment had more ($P$<0.08) live larvae at both sites than TF and TFS. At site 4, TCP was greater ($P$=0.03) than TS and at site 8, there was no difference ($P$=0.87) in ending larvae numbers between TCP and TS (Table 8; Appendix Table B). No difference ($P$>0.12) was detected between TF and TFS at either site. There was no difference ($P$=0.70) between TF and TS at site 4. At site 8, TS has more ($P$=0.01) larvae than TF. The TS plots had more ($P$<0.06) larvae than TFS at both sites (Table 8; Appendix Table B).

Table 7. Beginning treatment[a], change[a] and percent mortality[a] of wheat stem sawfly live larvae counts per 0.46m of row in control **(TC)**[b], clipped **(TCP)**[c], fall **(TF)**, spring **(TS)**, and fall+spring **(TSF)** trampled[d] plots at 2 sites[e] in Montana, taken October 2000, May 2001, September 2001, and May 2002.

| | | | Trampled | | | |
|---|---|---|---|---|---|---|
| | Control | Clipped | Fall | Spring | Fall+Spring | SE |
| Beginning treatment | $23.8^{x}$ | $26.2^{x}$ | $18.6^{y}$ | $25.5^{x}$ | $24.1^{x}$ | 1.83 |
| Change, live larvae | $-6.8^{x}$ | $-8.0^{xy}$ | $-8.3^{xy}$ | $-12.7^{yz}$ | $-16.5^{z}$ | 2.48 |
| Mortality, % | $31.4^{x}$ | $34.4^{xy}$ | $45.5^{xy}$ | $47.9^{y}$ | $69.6^{z}$ | 7.50 |

[a] No site x treatment interaction was detected ($P>0.28$)

[b] No input control

[c] Stubble clipped to 2.45 – 7.35 cm; conducted within 72h of fall trampling

[d] All sheep were muzzled while occupying a 111 m² plot for 24 hr (Fall+Spring 48h); Fall and Spring = 400 sheep d/ha, Fall+Spring = 800 sheep d/ha

[e] Sites located in Toole and Pondera counties

[x,y,z] Means within a row lacking a common superscript differ $P<0.10$

Table 8. Interaction[a] of site by treatment for ending treatment wheat stem sawfly counts per 0.46 m of row in control **(TC)**[b], clipped **(TCP)**[c], fall **(TF)**, spring **(TS)** and fall+spring **(TFS)** trampled[d] plots at 2 sites[e] in Montana, taken October 2000 through May 2001 and September 2001 through May 2002.

| | | | Trampled | | | |
|---|---|---|---|---|---|---|
| Site | Control | Clipped | Fall | Spring | Fall+Spring | SE |
| 4 | 28.0$^{z}$ | 29.0$^{z}$ | 18.8$^{xy}$ | 20.3$^{y}$ | 12.8$^{x}$ | 2.55 |
| 8 | 5.1$^{x}$ | 5.2$^{x}$ | 1.8$^{y}$ | 5.4$^{x}$ | 2.3$^{y}$ | 1.26 |

[a] Site x treatment interaction was detected ($P<0.02$)

[b] No input control

[c] Stubble clipped between 2 – 7cm; conducted within 72h of fall trampling

[d] All sheep were muzzled while occupying a 111m² plot for 24 hr (Fall+Spring 48h); Fall and Spring = 400 sheep d/ha, Fall+Spring = 800 sheep d/ha

[e] Sites located in Toole and Pondera counties

[x,y,z] Means within a row lacking a common superscript differ $P<0.10$

Change in WSS Larval Numbers. The site by treatment interaction was not significant ($P>0.90$) for change in live larvae (Table 7). Therefore, main effect of treatment across sites is presented.

No difference ($P=0.74$; $P=0.66$, respectively) in WSS larval numbers were detected from the beginning to the end of the experiment for change between TC and TCP or TC and TF respectively. The reduction ($P<0.07$) in live larvae was greater in TS and TFS than TC (Table 7).

Change in larval numbers did not differ ($P>0.16$) between TCP and TF or TS. There was a greater reduction ($P=0.01$) in TFS compared to TCP for change in live larvae (Table 7).

No differences were found in live larvae between TS when compared to TFS or TS. There was a greater reduction ($P=0.01$) in TFS compared to TF (Table 7).

Percent WSS Mortality. The site by treatment interaction was not significant ($P>0.90$) for percent mortality (Table 7). Therefore, main effect of treatment across sites is presented.

No difference ($P=0.78$) in percent mortality was detected between TC and TCP. There was no difference ($P=0.15$) between TC and TF. The TFS treatment had a higher ($P<0.01$) percent mortality than TC. Spring trample had a higher ($P<0.09$) percent mortality than TC (Table 7).

There were no differences ($P>0.18$) in percent mortality when comparing TCP with TF and TS. Percent mortality was greater in TFS than TCP (Table 7).

The TFS treatment had a higher ($P<0.01$) percent mortality when compared to TF and TS. There was no difference ($P=0.79$) detected between TF and TS for percent mortality (Table 7).

Discussion. Trampling disrupts the soil surface around the roots and causes damage to the stubs of the wheat plants. This allows for the freezing effects of winter and dampening of the stem around the larvae. Anslie (1920) and 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 overwinter but it does not turn the soil over like tillage. Instead it loosens the soil so it will not be as effective in insulating the WSS larvae. By trampling in the fall, we increased the stress of both the freezing and the drying effects of early winter at the time when the larvae is most vulnerable, which has been shown by Church (1955) to have the greatest effect on WSS larval mortality. Although according to Holmes (1954a) and Church (1955) the larvae are less susceptible to desiccation later in their lifecycle, we did not see any differences ($P=0.79$) between TF and TS. We did, however, find an increased ($P<0.01$) mortality in the TFS compared to TF and TS (Table 7). By doubling the stocking rate, and grazing in the fall and spring we increased the mortality 1.5 times.

The clipping which was designed to be similar to grazing without the trampling was not as effective as the trampling. Although there was some mortality in TCP plots (Table 7) it did not differ from TC.

## Soil Bulk Density

### Grazing Versus Control and Tillage Experiment

Beginning Soil Bulk Density. The site by treatment interaction was significant ($P<0.01$; Table 9; Appendix Table C). Therefore, results are presented as the simple effects of treatment within location.

Ending Soil Bulk Density. The site by treatment interaction was significant ($P<0.01$). Therefore, results are presented as the simple effects of treatment within location (Table 9; Appendix Table C).

At the end of the experiment, no differences ($P>0.55$) were detected at six sites between GC and GT. At the remaining two sites bulk density was greater ($P<0.05$) in GC than GT (Table 9; Appendix Table C).

Soil bulk density did not differ ($P>0.22$) between GC and GF at six of the eight sites at the end of the experiment At two sites, soil bulk density was greater ($P<0.01$) in GC than GF. There were no differences ($P>0.40$) in soil bulk density between GC and GS at seven sites (Table 9; Appendix Table C). At one site, soil bulk density was greater ($P=0.05$) in the GS treatment than the GC treatment. Soil bulk density did not differ ($P>0.33$) between GC and GFS at five sites, at the end of the experiment. At site 2, GC had less ($P=0.04$) soil bulk density than GFS. The GC treatment had greater ($P=0.08$) bulk density at sites 6 and 8 than GFS at the end of the experiment (Table 9; Appendix Table C).

Table 9. Interaction[a] of site x treatment for beginning treatment, ending treatment and change in soil bulk density ($Mg/m^3$) in control **(GC)**[b], tilled **(GT)**[c] fall **(GF)**, spring **(GS)**, and fall+spring **(GFS)** grazed[d] treatments October 2000, May 2001, September 2001, and through May 2002 at sites[e] in Montana.

| | | Grazed | | | | |
|---|---|---|---|---|---|---|
| Site | Control | Tilled | Fall | Spring | Fall+Spring | SE |
| Beginning treatment | | | | | | |
| 1 | $1.14^{xy}$ | $1.16^{xy}$ | $1.11^{y}$ | $1.28^{z}$ | $1.19^{x}$ | 0.03 |
| 2 | $1.13^{xy}$ | $1.09^{y}$ | $1.13^{xy}$ | $1.16^{x}$ | $1.15^{x}$ | 0.02 |
| 3 | $1.29^{xy}$ | $1.36^{y}$ | $1.25^{x}$ | $1.23^{x}$ | $1.36^{y}$ | 0.04 |
| 4 | 1.34 | 1.39 | 1.40 | 1.36 | 1.37 | 0.04 |
| 5 | $1.34^{xy}$ | $1.38^{x}$ | $1.32^{xy}$ | $1.29^{y}$ | $1.31^{y}$ | 0.03 |
| 6 | $1.45^{y}$ | $1.42^{y}$ | $1.39^{xy}$ | $1.33^{x}$ | $1.43^{y}$ | 0.03 |
| 7 | $1.32^{x}$ | $1.33^{x}$ | $1.36^{xy}$ | $1.34^{x}$ | $1.40^{y}$ | 0.02 |
| 8 | 1.38 | 1.37 | 1.38 | 1.36 | 1.37 | 0.02 |
| Ending treatment | | | | | | |
| 1 | $1.19^{x}$ | $1.20^{x}$ | $1.27^{xy}$ | $1.31^{y}$ | $1.19^{x}$ | 0.04 |
| 2 | $1.19^{x}$ | $1.16^{x}$ | $1.21^{xy}$ | $1.23^{xy}$ | $1.28^{y}$ | 0.03 |
| 3 | $1.24^{xy}$ | $1.26^{xy}$ | $1.21^{xy}$ | $1.17^{x}$ | $1.32^{y}$ | 0.06 |
| 4 | 1.38 | 1.35 | 1.34 | 1.34 | 1.32 | 0.04 |
| 5 | 1.35 | 1.33 | 1.32 | 1.37 | 1.36 | 0.03 |
| 6 | $1.50^{z}$ | $1.26^{x}$ | $1.36^{y}$ | $1.48^{wz}$ | $1.42^{wy}$ | 0.03 |
| 7 | 1.34 | 1.37 | 1.36 | 1.33 | 1.33 | 0.03 |
| 8 | $1.43^{w}$ | $1.35^{xy}$ | $1.25^{z}$ | $1.40^{wx}$ | $1.33^{y}$ | 0.03 |

[a] Site x treatment interaction was detected ($P<0.08$)

[b] No input control

[c] Shallow tillage (20 cm) was conducted within 72h of fall grazing

[d] Sheep grazed 111 $m^2$ plots for 24h (48h for Fall+Spring); Fall and Spring grazed at 400 sheep d/ha, Fall+Spring grazed at 800 sheep d/ha

[e] Sites located in Toole, Pondera, and Stillwater counties

[w,x,y,z] Means within a row lacking a common superscript differ $P<0.10$

Table 9 (cont). Interaction[a] of site x treatment for beginning treatment, ending treatment and change in soil bulk density ($Mg/m^3$) in control **(GC)**[b], tilled **(GT)**[c] fall **(GF)**, spring **(GS)**, and fall+spring **(GFS)** grazed[d] treatments October 2000, May 2001, September 2001, and through May 2002 at sites[e] in Montana.

| | | | Grazed | | | |
|---|---|---|---|---|---|---|
| Site | Control | Tilled | Fall | Spring | Fall+Spring | SE |
| Change | | | | | | |
| 1 | $0.06^{xy}$ | $0.05^{xy}$ | $0.16^{y}$ | $0.04^{x}$ | $0.00^{x}$ | 0.05 |
| 2 | 0.06 | 0.07 | 0.08 | 0.07 | 0.13 | 0.04 |
| 3 | -0.05 | -0.10 | -0.03 | -0.06 | -0.04 | 0.07 |
| 4 | 0.04 | -0.05 | -0.06 | -0.01 | -0.05 | 0.06 |
| 5 | $0.01^{xy}$ | $-0.04^{x}$ | $0.01^{xy}$ | $0.08^{y}$ | $0.05^{y}$ | 0.04 |
| 6 | $0.05^{xy}$ | $-0.17^{z}$ | $-0.03^{y}$ | $0.15^{x}$ | $-0.01^{y}$ | 0.04 |
| 7 | $0.03^{x}$ | $0.04^{x}$ | $0.00^{xy}$ | $-0.01^{xy}$ | $-0.07^{y}$ | 0.03 |
| 8 | $0.05^{z}$ | $-0.02^{yz}$ | $-0.13^{x}$ | $0.04^{z}$ | $-0.05^{y}$ | 0.03 |

[a] Site x treatment interaction was detected ($P<0.08$)

[b] No input control

[c] Shallow tillage (20 cm) was conducted within 72h of fall grazing

[d] Sheep grazed 111 $m^2$ plots for 24h (48h for Fall+Spring); Fall and Spring grazed at 400 sheep d/ha, Fall+Spring grazed at 800 sheep d/ha

[e] Sites located in Toole, Pondera, and Stillwater counties

[w,x,y,z] Means within a row lacking a common superscript differ $P<0.10$

At six out of eight sites, soil bulk density did not differ ($P>0.30$) between GT and GF at the end of the experiment. At one site, GT ending soil bulk density was greater ($P=0.02$) than GF. At the other sites, GF was greater ($P<0.01$). There was no difference ($P>0.14$) between GT and GS at six sites and at two sites GS was greater ($P=0.07$). In GT versus GFS, there were no differences ($P>0.28$) at six sites. Fall and spring combined graze was greater ($P<0.03$) at two sites than GT (Table 9; Appendix Table C).

At the end of the experiment, when comparing the grazing treatments among each other, GF versus GS and GFS there were no differences ($P>0.11$) in soil bulk density at six and seven sites, respectively. At five sites, there were no differences ($P>0.22$) in bulk density between GS and GFS at the end of the experiment. At two sites, GS soil bulk density was greater ($P<0.09$) than both GF and GFS. Soil bulk density was lower ($P<0.06$) in GF, at one site, than GFS, at the end of the experiment (Table 9; Appendix Table C).

Change in Soil Bulk Density. The site by treatment interaction was significant ($P<0.01$). Therefore, the results are presented as the simple effects of treatment within location (Table 9; Appendix Table C).

At seven out of eight sites there were no differences in change of soil bulk density ($P>0.11$) between GC and GT. At one site GT and GC differed ($P<0.01$). There was a reduction in GT and an increase in GC (Table 9; Appendix Table C).

There were no differences ($P>0.17$) detected in soil bulk density change between GC and GF at seven sites. There was a difference ($P<0.01$) at one site where

bulk density increased in GC and decreased in GF. Soil bulk density change did not differ ($P>0.12$) at any of the eight sites between GC versus GS. In the comparison of GC and GFS, at six sites there were no differences ($P>0.16$) for soil bulk density change (Table 9; Appendix Table C). At two sites GC and GFS differed ($P<0.03$), soil bulk density increased in GC and decreased in GFS (Table 9; Appendix Table C).

Soil bulk density change at six sites, did not differ ($P>0.12$) between GT and GF. At the other two sites results for soil bulk density change were mixed, at site 6, GT had a greater ($P=0.03$) reduction than GF and at site 8, GF had a greater reduction ($P=0.03$) than GT. When comparing GT versus GS, at six sites there were no differences ($P>0.22$) in soil bulk density change (Table 9; Appendix Table C). Spring graze and GT differed ($P<0.03$) at two sites where soil bulk density increased in GS and decreased in GT. For GT to GSF, at five sites there were no differences ($P>0.28$) in soil bulk density change. At site 5 there was a difference ($P<0.10$) between GT and GFS, where GT soil density decreased and GFS increased. At site 6 there was a greater reduction in soil bulk density for GT than GFS ($P<0.10$). Tilled and GFS differed ($P=0.02$) at site 7, soil bulk density increased in GT and decreased in GFS (Table 9; Appendix Table C).

Soil bulk density change results were mixed among grazing treatments. In GF versus GS, at five sites there were no differences ($P>0.18$) in soil bulk density change. At site 1, GF soil bulk density change was increased more ($P=0.10$) than GS. Fall grazed and GS differed ($P<0.01$) at sites 6 and 8, GF soil bulk density was decreased and in GS it increased. Comparing GF with GFS, at seven sites there were no

differences ($P$>0.10) in soil bulk density change. At site 1, GF soil bulk density change was increased ($P$<0.03) and in GFS it did not change. At six sites, there were no differences ($P$>0.20) when comparing soil bulk density change of GS to GFS. At sites 6 and 8, GS soil bulk density increased in GS and decreased in GFS ($P$<0.08;Table 9; Appendix Table C).

Fall Burned Versus Control, Fall Grazed, and Tilled Experiment

Beginning Soil Bulk Density. The site by treatment interaction was not significant ($P$=0.68; Table 10). Therefore, main effect of treatment across sites is presented.

Ending Soil Bulk Density. The site by treatment interaction was significant ($P$<0.01; Table 11; Appendix Table D). Therefore, results are presented as the simple effects of treatment within location.

At five of the six sites no differences were detected ($P$>0.36) in ending soil bulk density between BC and BB. At site 6, ending soil bulk density was greater ($P$<0.01) for BC than BB (Table 11; Appendix Table D).

Ending soil bulk density did not differ ($P$>0.54) between BT and BB at five of the six sites. At site 6, BT had greater ($P$<0.01) ending soil bulk density than BB (Table 11; Appendix Table D).

Table 10. Soil bulk density ($Mg/m^3$) for beginning treatment[a] in control **(BC)**[b], tilled **(BT)**[c], burned **(BB)**[d], and fall grazed **(BF)**[e] treatments from October 2000, May 2001, September 2001, and May 2002, at 8 combined sites[f] in Montana.

| | Control | Tilled | Burned | Fall Grazed | SE |
|---|---|---|---|---|---|
| Beginning treatment | 1.35 | 1.38 | 1.37 | 1.35 | 0.01 |

[a] No site x treatment interaction was detected ($P$=0.55)
[b] No input control
[c] Shallow tillage (20 cm) was conducted within 72h of fall grazing
[d] Burning was conducted within 72h of fall grazing[e] Sheep grazed 111 $m^2$ plots for 24h
[f] Sites located in Toole, Pondera, and Stillwater counties

Table 11. Interaction[a] of site x treatment for ending treatment and change in soil bulk density ($Mg/m^3$) in control **(BC)**[b], tilled **(BT)**[c], burned **(BB)**[d], and fall grazed **(BF)**[e] treatments October 2000, May 2001, September 2001, and May 2002 at 8 sites[e] in Montana.

| | Control | Tilled | Burned | Fall Grazed | SE |
|---|---|---|---|---|---|
| Ending treatment | | | | | |
| 3 | 1.24 | 1.27 | 1.26 | 1.21 | 0.05 |
| 4 | 1.38 | 1.33 | 1.35 | 1.34 | 0.04 |
| 5 | 1.35 | 1.33 | 1.33 | 1.32 | 0.03 |
| 6 | $1.50^{z}$ | $1.46^{z}$ | $1.26^{x}$ | $1.36^{y}$ | 0.03 |
| 7 | 1.34 | 1.35 | 1.37 | 1.36 | 0.03 |
| 8 | $1.43^{z}$ | $1.33^{y}$ | $1.35^{y}$ | $1.25^{x}$ | 0.03 |
| Change | | | | | |
| 3 | -0.05 | -0.10 | -0.04 | -0.03 | 0.07 |
| 4 | 0.04 | -0.05 | 0.01 | -0.06 | 0.06 |
| 5 | 0.01 | -0.04 | -0.07 | 0.01 | 0.05 |
| 6 | $0.05^{x}$ | $-0.17^{y}$ | $0.03^{x}$ | $-0.03^{x}$ | 0.04 |
| 7 | 0.03 | 0.04 | 0.00 | 0.00 | 0.03 |
| 8 | $0.05^{x}$ | $-0.02^{xz}$ | $-0.06^{yz}$ | $-0.13^{y}$ | 0.04 |

[a] Site x treatment interaction was detected ($P<0.03$)
[b] No input control
[c] Shallow tillage (20 cm) was conducted within 72h of fall grazing
[d] Burning was conducted within 72h of fall grazing
[e] Sheep grazed 111 $m^2$ plots for 24h
[f] Sites located in Toole, Pondera, and Stillwater counties
[x,y,z] Means within a row lacking a common superscript differ $P<0.10$

No differences ($P>0.39$) were detected in ending soil bulk density between BB and BF at four sites of the six sites. At site 6, BB had lower ($P<0.06$) bulk density and at site 8 a greater ending bulk density than BF (Table 11; Appendix Table D).

Change in Soil Bulk Density. The site by treatment interaction was significant ($P=0.03$; Table 11; Appendix Table D). Therefore, results are presented as the simple effects of treatment within location.

No differences ($P>0.20$) were detected in soil bulk density change between BC and BB at five out of the six sites. At site 8, soil bulk density increased in BC and decreased in BB ($P=0.03$; Table 11; Appendix Table D).

Soil bulk density change did not differ ($P>0.37$) between BT and BB at five of the six sites. At site 6, BB and BT differed ($P<0.02$), soil bulk density increased in BB and decreased in BT (Table 11; Appendix Table D).

There were no differences ($P>0.19$) in soil bulk density change at any of the six sites between BB and BF (Table 11; Appendix Table D).

Trample Versus Control and Clip Experiment

Beginning Soil Bulk Density. The site by treatment interaction was not significant ($P=0.91$; Table 12). Therefore, main effects of treatment across sites are presented.

Table 12. Soil bulk density ($Mg/m^3$) in beginning treatment[a], ending treatment[a], and control (TC)[b], clipped (TCP)[c], fall (TF), spring (TS), and fall+spring (TSF) trampled[d] treatments from October 2000, May 2001, September 2001, and May 2002, at 2 combined sites[e] in Montana.

| | | | Trampled | | | |
|---|---|---|---|---|---|---|
| | Control | Clipped | Fall | Spring | Fall+Spring | SE |
| Beginning treatment | $1.36^{xy}$ | $1.32^{x}$ | $1.39^{y}$ | $1.32^{x}$ | $1.37^{xy}$ | 0.02 |
| Ending treatment | $1.41^{x}$ | $1.35^{y}$ | $1.36^{xy}$ | $1.37^{xy}$ | $1.36^{xy}$ | 0.02 |
| Change | $0.04^{xy}$ | $0.03^{xy}$ | $-0.02^{y}$ | $0.05^{x}$ | $-0.01^{xy}$ | 0.03 |

[a] No site x treatment interaction was detected ($P>0.78$ )

[b] No input control.

[c] Stubble clipped between 2 – 7cm; conducted within 72h of fall trampling

[d] All sheep were muzzled while occupying a 111 $m^2$ plot for 24hr (Fall+Spring 48h); Fall and Spring = 400 sheep d/ha, Fall+Spring = 800 sheep d/ha

[e] Sites located in Toole and Pondera counties

[x,y] Means within a row lacking a common superscript differ $P<0.10$

Ending Soil Bulk Density. The site by treatment interaction was not significant ($P$=0.80; Table 12). Therefore, main effects of treatment across sites are presented. Ending soil bulk density was greater ($P$<0.09) in TC than TCP (Table 12).

There was no difference ($P$>0.17) between trample treatments and TC. Clip did not differ ($P$>0.47) when compared to TF, TS, or TFS. No differences ($P$>0.67) were detected in ending soil bulk density among TF, TS, and TFS (Table 12).

Change in Soil Bulk Density. The site by treatment interaction was not significant ($P$=0.91; Table 12). Therefore, main effects of treatment across sites is presented.

No difference was detected ($P$=0.75) for bulk density change between TC and TCP from the beginning to the end of the experiment. Bulk density change did not differ ($P$>0.13) between TC, and TF, TS, or TFS (Table 12).

There were no differences ($P$>0.23) between TF, TS, TFS, and TCP. Soil bulk density change for TFS did not differ ($P$>0.14) from TF or TS. Soil bulk density increased in TS and decreased in TF ($P$=0.08; Table 12).

Discussion. Drewry et al. (1999) and Murphy et al. (1995) reported that sheep grazing in irrigated pastures had no long-term detrimental effects on soil compaction. Our results agree with their findings. Overall we found no differences in soil compaction among the GC, GT, GF, and GFS treatments. This may be due to the freezing and thawing of the soil over winter (Brady and Weil, 1999). With reduced biomass to protect the soil from freezing the grazing treatments may be more

susceptible to temperature changes. In this way, the soil particles may be broken apart by the expanding of the freezing water between them. Hoof action may have also contributed to the lack of soil compaction. The hooves of the sheep churn up the soil at the surface.

No differences were found between BC, BB, and BT treatments. Reduction of biomass in the grazed treatments may increase the freezing and thawing of the soil and reduce soil compaction. The hooves of the sheep may have also broken up the soil similar to tillage.

Murphy et al (1995a) found soil compaction was 81% greater under cattle grazing than sheep grazing at the same stocking rate. Compaction may be increased in the spring treatment plots possibly due to the soil not being exposed to the same freezing and thawing effects of winter. Due to the increased soil moisture in the spring particles may become compressed together from hoof action rather than the churned up as in the fall when there is less soil moisture. However, our soil bulk density throughout the trial remained within the acceptable range of bulk density for cultivated clay loam soils, the range is 0.9 to 1.5 $Mg/m^3$, our soils fell into a range of 1.19 to 1.43 $Mg/m^3$ for both beginning treatment and ending treatment bulk density (Chancellor, 1977; Brady and Weil, 1999).

More research is needed to determine the exact reasons for sheep not increasing soil bulk density in the way cattle do (Murphy, 1995a). It can be speculated that the shape and small size of the hoof may actually churn and till up the soil rather than compressing it down.

## Biomass and Weeds

### Biomass

#### Grazing Versus Control and Tillage Experiment.

Beginning Biomass. The site by treatment interaction was significant ($P<0.05$) for beginning biomass (Table 13; Appendix Table E). Therefore, main effects of treatment across sites are presented.

Ending Biomass. The site by treatment interaction was not significant ($P=0.16$; Table 14) for ending biomass. Therefore, main effects of treatment across sites are presented.

Control plots had a greater ($P<0.01$) amount of ending biomass than GT (Table 14). There was a greater ($P<0.01$) amount of ending biomass in GC than any of the grazing treatments (Table 14). No differences ($P>0.15$) were detected in ending biomass when GT was compared to GF or GS. Tilled plots had a greater ($P<0.01$) amount of ending biomass than GFS (Table 14). No differences ($P=0.36$) in ending biomass were detected between GF and GS. Ending biomass was less ($P<0.03$) in GFS than GF and GS (Table 14).

Change in Biomass. The site by treatment interaction was significant for change in amount of biomass ($P<0.01$; Table 13; Appendix Table E). Therefore, results are presented as the simple effects of treatment within location.

Table 13. Interaction[a] of site by treatment for beginning, change in weight (g), percent change, and percent remaining of biomass in control **(GT)**[b], tilled **(GT)**,[c] fall **(GF)**, spring **(GS)**, and fall+spring grazed **(GFS)**[d] plots at 8 sites[e] in Montana, taken October 2000 through May 2001 and September 2001 through May 2002.

| | | | Grazed | | | |
|---|---|---|---|---|---|---|
| Site | Control | Tilled | Fall | Spring | Fall+Spring | SE |
| Beginning treatment, g | | | | | | |
| 1 | $46.4^{xy}$ | $50.3^{x}$ | $53.2^{x}$ | $36.7^{y}$ | $53.3^{x}$ | 4.30 |
| 2 | 49.0 | 43.6 | 44.9 | 46.4 | 46.3 | 3.13 |
| 3 | $50.2^{x}$ | $39.8^{x}$ | $47.5^{x}$ | $61.2^{y}$ | $41.3^{x}$ | 4.22 |
| 4 | 49.0 | 60.8 | 61.2 | 52.3 | 60.4 | 5.38 |
| 5 | 28.9 | 33.3 | 32.1 | 31.4 | 31.3 | 4.21 |
| 6 | 34.5 | 34.5 | 28.5 | 24.9 | 28.1 | 4.86 |
| 7 | $25.2^{xy}$ | $35.6^{y}$ | $24.4^{xy}$ | $20.3^{x}$ | $21.8^{x}$ | 5.19 |
| 8 | 19.5 | 24.0 | 18.2 | 24.3 | 17.0 | 3.77 |
| Change, weight | | | | | | |
| 1 | $-4.9^{z}$ | $-23.3^{y}$ | $-23.8^{xy}$ | $-12.3^{z}$ | $-32.6^{x}$ | 3.61 |
| 2 | $-5.4^{x}$ | $-17.5^{xz}$ | $-29.9^{yz}$ | $-36.3^{y}$ | $-34.2^{y}$ | 5.02 |
| 3 | $-5.9^{z}$ | $-12.1^{yz}$ | $-11.5^{z}$ | $-41.2^{x}$ | $-26.7^{xy}$ | 6.03 |
| 4 | $-2.3^{z}$ | $-35.8^{y}$ | $-36.8^{xy}$ | $-34.3^{y}$ | $-50.4^{x}$ | 5.56 |
| 5 | $4.2^{x}$ | $-20.7^{y}$ | $-13.1^{y}$ | $-11.7^{y}$ | $-19.6^{y}$ | 5.60 |
| 6 | $-3.0^{z}$ | $-17.6^{xy}$ | $-19.6^{xy}$ | $-8.3^{yz}$ | $-25.4^{x}$ | 5.24 |
| 7 | $-11.3^{y}$ | $-27.2^{x}$ | $-17.9^{xy}$ | $-11.6^{y}$ | $-18.8^{xy}$ | 5.40 |
| 8 | $20.8^{x}$ | $-5.7^{y}$ | $-7.0^{y}$ | $-11.7^{y}$ | $-10.9^{y}$ | 7.16 |

[a] Site x treatment interaction was detected ($P<0.10$)

[b] No input control

[c] Shallow tillage (20 cm ) was conducted within 72h of fall grazing

[d] Sheep grazed 111m² plots for 24h (48h for Fall+Spring); Fall and Spring grazed at 400 sheep d/ha, Fall+Spring grazed at 800 sheep d/ha

[e] Sites located in Toole, Pondera, and Stillwater counties

[w,x,y,z] Means within a row lacking a common superscript differ $P<0.10$

Table 13 (cont.). Interaction[a] of site by treatment for beginning, change in weight (g), percent change, and percent remaining of biomass in control (GT)[b], tilled (GT),[c] fall (GF), spring (GS), and fall+spring grazed (GFS)[d] plots at 8 sites[e] in Montana, taken October 2000 through May 2001 and September 2001 through May 2002.

| | | | Grazed | | | |
|---|---|---|---|---|---|---|
| Site | Control | Tilled | Fall | Spring | Fall+Spring | SE |
| Change, %[1] | | | | | | |
| 1 | -9.2$^{w}$ | -45.8$^{z}$ | -43.5$^{yz}$ | -32.6$^{y}$ | -61.0$^{x}$ | 5.26 |
| 2 | -11.1$^{x}$ | -39.6$^{y}$ | -64.6$^{z}$ | -77.4$^{z}$ | -74.7$^{z}$ | 8.61 |
| 3 | -10.3$^{y}$ | -31.5$^{y}$ | -26.3$^{y}$ | -64.9$^{x}$ | -63.8$^{x}$ | 10.61 |
| 4 | -6.0$^{x}$ | -58.6$^{z}$ | -59.4$^{z}$ | -64.0$^{z}$ | -83.5$^{y}$ | 7.22 |
| 5 | 14.6$^{x}$ | -56.3$^{y}$ | -40.9$^{y}$ | -37.0$^{y}$ | -62.9$^{y}$ | 15.43 |
| 6 | -4.3$^{w}$ | -53.2$^{yz}$ | -69.9$^{xy}$ | -33.9$^{wz}$ | -90.1$^{x}$ | 13.14 |
| 7 | -44.5$^{z}$ | -74.3$^{xy}$ | -67.9$^{xyz}$ | -55.0$^{yz}$ | -83.8$^{x}$ | 9.59 |
| 8 | 113.3$^{x}$ | -3.2$^{y}$ | -29.2$^{y}$ | -47.0$^{y}$ | -56.6$^{y}$ | 31.43 |
| Remaining, % | | | | | | |
| 1 | 90.8$^{w}$ | 54.2$^{x}$ | 56.5$^{xy}$ | 67.4$^{y}$ | 39.0$^{z}$ | 5.26 |
| 2 | 88.9$^{x}$ | 60.4$^{y}$ | 35.4$^{z}$ | 22.6$^{z}$ | 25.3$^{z}$ | 8.61 |
| 3 | 89.7$^{x}$ | 68.5$^{x}$ | 73.7$^{x}$ | 35.1$^{y}$ | 36.2$^{y}$ | 10.61 |
| 4 | 94.0$^{z}$ | 41.4$^{y}$ | 40.7$^{y}$ | 36.0$^{y}$ | 16.5$^{x}$ | 7.22 |
| 5 | 114.6$^{x}$ | 43.7$^{y}$ | 59.1$^{y}$ | 63.0$^{y}$ | 38.1$^{y}$ | 15.43 |
| 6 | 95.7$^{w}$ | 46.8$^{yz}$ | 30.1$^{xy}$ | 66.2$^{wz}$ | 9.9$^{x}$ | 13.14 |
| 7 | 55.5$^{z}$ | 25.7$^{xy}$ | 32.1$^{xz}$ | 45.0$^{yz}$ | 16.2$^{x}$ | 9.59 |
| 8 | 213.3$^{x}$ | 96.8$^{y}$ | 70.9$^{y}$ | 53.0$^{y}$ | 43.5$^{y}$ | 31.44 |

[a] Site x treatment interaction was detected ($P<0.10$)

[b] No input control

[c] Shallow tillage (20 cm ) was conducted within 72h of fall grazing

[d] Sheep grazed 111m² plots for 24h (48h for Fall+Spring); Fall and Spring grazed at 400 sheep d/ha, Fall+Spring grazed at 800 sheep d/ha

[e] Sites located in Toole, Pondera, and Stillwater counties

[w,x,y,z] Means within a row lacking a common superscript differ $P<0.10$

Table 14. Ending[a] biomass (g) in control **(GC)**[b], tilled **(GT)**[c], Fall **(GF),** spring **(GS),** and fall+spring **(GFS)** grazed[d] plots at 8 combined sites[e] in Montana, taken October 2000 through May 2001 and September 2001 through May 2002.

| | | | Grazed | | | |
|---|---|---|---|---|---|---|
| | Control | Tilled | Fall | Spring | Fall+Spring | SE |
| Ending treatment | 36.9[x] | 20.3[z] | 18.8[z] | 16.3[z] | 10.1[y] | 1.97 |

[a] No site x treatment interaction was detected ($P$=0.16)
[b] No input control
[c] Shallow tillage (20 cm) was conducted within 72h of fall grazing
[d] Sheep grazed 111m² plots for 24h (48h for Fall+Spring); Fall and Spring grazed at 400 sheep d/ha, Fall+Spring grazed at 800 sheep d/ha
[e] Sites located in Toole, Pondera, and Stillwater counties
[x,y,z] Means within a row lacking a common superscript differ $P$<0.10

Control had less reduction ($P<0.05$) in biomass at four sites than GT from the beginning to the end of the experiment. There was a difference ($P<0.02$) at two sites, change in biomass increased in GC and decreased in GT. At two sites there were no differences ($P>0.12$; Table 13; Appendix Table E). Control had a less reduction ($P<0.01$) than GF at three sites. At two sites GC and GF differed ($P<0.05$), GC increased and GF decreased. Control and GF were not different ($P>0.40$) at two sites for change in biomass from the beginning to the end of the experiment. At three out of the eight sites, GC had less reduction ($P<0.01$) in biomass than GS (Table 13; Appendix Table E). At two sites GC and GS differed ($P<0.06$), GC had an increase in biomass and GS a reduction. At three sites there were no differences ($P>0.17$) between GC and GS for change in biomass. At five out of eight sites biomass was reduced more ($P<0.03$) in GFS than GC. Control and GFS differed ($P<0.01$) at two sites, biomass increased in GC and decreased in GFS. There was no difference ($P=0.34$) for change in the amount of biomass between GC and GFS at one site (Table 13; Appendix Table E).

The change in biomass did not differ ($P>0.10$) between GT and GF at all eight sites from the beginning to the end of the experiment. Results were mixed for change in biomass comparing GT with GS. At four sites there were no differences ($P>0.20$) in change, at two sites GT had more of an increase ($P<0.05$) in biomass than GS and at two sites GS had more of an increase ($P<0.06$) in biomass than GT (Table 13; Appendix Table E). At five sites, there were no differences in change of biomass

($P$>0.12) between GT and GFS. At three sites, GFS had a more of a reduction ($P$<0.08) for change in biomass than GT (Table 13; Appendix Table E).

When comparing the change in biomass for grazing treatments, in GF to GS at six sites there were no differences ($P$>0.12). There was a difference ($P$<0.01) at site 1, GF had a greater reduction in biomass than GS (Table 13; Appendix Table E). At site 3, there was a greater reduction ($P$=0.04) in biomass in GS than GF. At seven out of the eight sites, there were no differences ($P$>0.10) between GF and GFS in the change of biomass. There was a greater reduction ($P$<0.10) for biomass in GFS than GF, at site 3. Comparing change in biomass between GS and GFS, at five sites there were no differences ($P$>0.11). At three sites, GSF had less of a reduction ($P$<0.06) than GS (Table 13; Appendix Table E).

Percent Biomass Remaining. The site by treatment interaction was significant ($P$<0.01) for percent biomass remaining (Table 13; Appendix Table E) Therefore, results are presented as the simple effects of treatment within location.

At seven out of eight sites GC had a higher ($P$<0.04) percent biomass remaining than GT. At site 3, there was no difference ($P$=0.18) between GC and GT for percent biomass remaining (Table 13; Appendix Table E). Control had a higher ($P$<0.04) percent biomass remaining than GF and GS at six sites. At two sites, there were no differences ($P$>0.11) in percent biomass remaining between GC and GF or GS. At all eight sites GC had a higher ($P$<0.01) percent biomass remaining than GFS (Table 13; Appendix Table E).

There were no differences ($P$>0.22) at seven out of the eight sites for percent biomass remaining when GT was compared with GF. At one site, GT had greater ($P$<0.07) percent biomass remaining than GF. At two sites, GT had greater ($P$<0.04) percent biomass remaining than GS, and at one site it was less ($P$=0.10). At five sites GT was higher ($P$<0.06) than GFS and at three sites there were no differences ($P$>0.19) between GT and GFS (Table 13; Appendix Table E).

Percent biomass remaining did not differ ($P$>0.35) between GF and GS at six sites. At site 3, GF was greater ($P$=0.08) than GS. At site 6, GS had a greater ($P$=0.07) percent biomass remaining than GF. Comparing GFS with GF at five sites there were no differences ($P$>0.23). At three sites; GF had a greater ($P$<0.02) percent biomass remaining than GFS. At four sites, there were no differences ($P$>0.27) between GFS and GS. The GS treatment had a greater ($P$<0.08) percent remaining than GFS at four sites (Table 13; Appendix Table E).

Fall Burned Versus Control, Fall Grazed, and Tilled Experiment

Beginning Biomass. The site by treatment interaction was not significant ($P$=0.72; Table 15) in beginning biomass. Therefore, main effects of treatment across sites are presented.

Ending Biomass. The site by treatment interaction was not significant ($P$=0.13; Table 15) for ending amount of biomass. Therefore, main effect of treatment across sites is presented. Control had greater ($P$<0.01) amount of ending biomass than BB (Table 15). There was no difference ($P$=0.76) in ending amount of biomass

Table 15. Beginning[a] (g), ending[a] (g), change [a] in weight (g) of biomass in control **(BC)**[b], tilled **(BT)**[c], burned **(BB)**[d], and fall grazed **(BF)**[e] plots at 8 combined sites[f] in Montana, taken October 2000 through May 2001 and September 2001 through May 2002.

| | Control | Tilled | Burned | Fall Grazed | SE |
|---|---|---|---|---|---|
| Beginning treatment | 34.5 | 38.0 | 32.1 | 35.3 | 3.21 |
| Ending treatment | 35.0$^{x}$ | 18.2$^{y}$ | 17.1$^{y}$ | 17.7$^{y}$ | 2.52 |
| Change, weight | 0.4$^{x}$ | -19.9$^{y}$ | -15.0$^{y}$ | -17.7$^{y}$ | 3.11 |

[a] No site x treatment interaction was detected ($P$>0.12)
[b] No input control
[c] Shallow tillage (20 cm) was conducted within 72h of fall grazing
[d] Burning was conducted within 72h of fall grazing[e] Sheep grazed 111m² plots for 24h
[f] Sites located in Toole, Pondera, and Stillwater counties
[x,y] Means within a row lacking a common superscript differ $P$<0.10

between BB and BT Ending biomass was not different ($P$=0.89) between BB and BF (Table 15).

Change in Biomass. The site by treatment interaction was not significant ($P$=0.13; Table 15) for change in the amount of biomass in burn treatment sites. Therefore, main effects of treatment across sites are presented.

Control and BB differed ($P$<0.01), BC had an increase in biomass and BB decreased in the amount of biomass. The change in biomass did not differ ($P$=0.27) from the beginning to the end of the experiment between BB and BT. No differences were detected ($P$=0.54) between BB and BF (Table 15).

Percent Biomass Remaining. A site by treatment interaction was detected ($P$=0.10) for percent biomass remaining (Table 16; Appendix Table F). Therefore, results are presented as the simple effects of treatment within location.

At five out of six sites BC had a greater ($P$<0.06) percent biomass remaining than BB. At site 7, there was no difference ($P$=0.66) in percent biomass remaining. There was no difference ($P$>0.15) between BT and BB at five sites. The BB treatment had greater ($P$=0.01) percent biomass remaining at site 7 than BT. Percent biomass remaining results were mixed when comparing BB with BF. At four out of the six sites there were no differences ($P$>0.15) between BB and BF. At site 7, BB had greater ($P$=0.03) percent biomass remaining than BF. At site 3, BF had greater ($P$=0.09) percent biomass remaining than BB (Table 16; Appendix Table F).

Table 16. Interaction[a] of site by treatment for change in weight (g) and percent remaining of biomass in control (**BC**)[b], tilled (**BT**)[c], burned (**BB**)[d] and fall grazed (**BF**)[e] plots at 8 sites[f] in Montana, taken October 2000 through May 2001 and September 2001 through May 2002.

| Site | Control | Tilled | Burned | Fall Grazed | SE |
|---|---|---|---|---|---|
| Change, % | | | | | |
| 3 | -10.29$^{x}$ | -31.52$^{xy}$ | -59.33$^{y}$ | -26.27$^{x}$ | 13.64 |
| 4 | -6.02$^{x}$ | -58.58$^{y}$ | -68.67$^{y}$ | -59.35$^{y}$ | 6.70 |
| 5 | 14.57$^{x}$ | -56.32$^{y}$ | -29.54$^{y}$ | -40.93$^{y}$ | 13.20 |
| 6 | -4.30$^{x}$ | -53.19$^{y}$ | -42.20$^{y}$ | -69.92$^{y}$ | 13.05 |
| 7 | -44.51$^{x}$ | -74.32$^{y}$ | -39.26$^{x}$ | -67.90$^{y}$ | 8.18 |
| 8 | 113.27$^{x}$ | -3.21$^{y}$ | 5.32$^{y}$ | -29.15$^{y}$ | 35.52 |
| Remaining, % | | | | | |
| 3 | 89.71$^{x}$ | 68.48$^{xy}$ | 40.67$^{y}$ | 73.73$^{x}$ | 13.64 |
| 4 | 93.98$^{x}$ | 41.42$^{y}$ | 31.33$^{y}$ | 40.65$^{y}$ | 6.70 |
| 5 | 114.58$^{x}$ | 43.68$^{y}$ | 70.46$^{y}$ | 59.07$^{y}$ | 13.20 |
| 6 | 95.70$^{x}$ | 46.81$^{y}$ | 57.80$^{y}$ | 30.08$^{y}$ | 13.05 |
| 7 | 55.49$^{x}$ | 25.68$^{y}$ | 61.74$^{x}$ | 32.10$^{y}$ | 8.18 |
| 8 | 213.27$^{x}$ | 96.79$^{y}$ | 105.32$^{y}$ | 70.85$^{y}$ | 35.52 |

[a] Site x treatment interaction was detected ($P<0.10$)
[b] No input control
[c] Shallow tillage (20 cm) was conducted within 72h of fall grazing
[d] Burning was conducted within 72h of fall grazing
[e] Sheep grazed 111m² plots for 24h
[f] Sites located in Toole, Pondera, and Stillwater counties
[x,y] Means within a row lacking a common superscript differ $P<0.10$

Trample Versus Control and Clip Experiment

Beginning Biomass. The site by treatment interaction was not significant ($P$=0.13; Table 17) for beginning biomass. Therefore, main effects of treatment across sites are presented.

Ending Biomass. The site by treatment interaction was significant ($P$<0.01) for the amount of ending biomass (Table 18; Appendix Table G). Therefore, results are presented as the simple effects of treatment within location.

Ending biomass was greater ($P$<0.01) in TC than TCP, at site 4. At site 8, there was no difference ($P$=0.28) between TC and TCP (Table 18; Appendix Table G). Control had a greater ($P$<0.01) amount of ending biomass at site 8, than TF, TS or TFS. At site 4, there was no difference ($P$>0.65) between TC and TF, TS or TFS (Table 18; Appendix Table G).

The ending amount of biomass was greater ($P$<0.01) in TF, TS, and TFS than TCP at site 4. At site 8, there was no difference ($P$=0.11) between TCP and TS. Ending biomass was greater ($P$<0.01) in TCP than TF or TFS at site 8 There were no differences ($P$>0.23) in ending biomass among the trample treatments (Table 18; Appendix Table G).

Change in Biomass. The site by treatment interaction was significant ($P$=0.09; Table 18; Appendix Table G) for the change in the amount of biomass. Therefore, results are presented as the simple effects of treatment within location.

Table 17. Beginning[a] (g), of biomass in control (TC)[b], clipped (TCP)[c], fall (TF), spring (TS), and fall+spring (TFS) trampled[d] plots at 2 combined sites[e] in Montana, taken October 2000 through May 2001 and September 2001 through May 2002.

| | | | Trampled | | | |
|---|---|---|---|---|---|---|
| | Control | Clipped | Fall | Spring | Fall+Spring | SE |
| Beginning treatment | 34.23 | 35.79 | 35.82 | 44.34 | 41.65 | 7.26 |

[a] No site x treatment interaction was detected ($P$=0.13)

[b] No input control

[c] Stubble clipped to 2.45 – 7.35 cm; conducted within 72h of fall trampling

[d] All sheep were muzzled while occupying a 111m² plot for 24hr (Fall+Spring 48h); Fall and Spring = 400 sheep d/ha, Fall+Spring = 800 sheep d/ha

[e] Sites located in Toole and Pondera counties

Table 18. Interaction[a] of site by treatment for ending, change in weight (g), change in percent, and change in percent remaining of biomass in control **(TC)**[b], clipped **(TCP)**[c], fall **(TF)**, spring **(TS)**, and fall+spring **(TFS)** trampled[d] plots at 2 sites[e] in Montana, taken October 2000 through May 2001 and September 2001 through May 2002.

| | | | Trampled | | | |
|---|---|---|---|---|---|---|
| Site | Control | Clipped | Fall | Spring | Fall+Spring | SE |
| Ending treatment | | | | | | |
| 4 | $46.75^{x}$ | $20.75^{y}$ | $45.17^{x}$ | $43.25^{x}$ | $43.00^{x}$ | 5.74 |
| 8 | $40.26^{z}$ | $32.28^{yz}$ | $16.57^{x}$ | $20.38^{xy}$ | $11.44^{x}$ | 5.03 |
| Change, weight | | | | | | |
| 4 | $-2.25^{z}$ | $-28.25^{x}$ | $-8.50^{yz}$ | $-20.91^{x}$ | $-21.33^{xy}$ | 5.20 |
| 8 | $20.80^{z}$ | $9.70^{yz}$ | $-1.40^{xy}$ | $-4.14^{xy}$ | $-7.53^{x}$ | 5.76 |
| Change, % | | | | | | |
| 4 | $-6.02^{x}$ | $-58.36^{y}$ | $-14.36^{xz}$ | $-30.62^{z}$ | $-33.65^{z}$ | 8.88 |
| 8 | $113.27^{x}$ | $56.49^{x}$ | $3.36^{yz}$ | $-17.41^{z}$ | $-31.81^{z}$ | 29.69 |
| Remaining, % | | | | | | |
| 4 | $93.98^{z}$ | $41.64^{x}$ | $85.64^{yz}$ | $69.38^{y}$ | $66.35^{y}$ | 8.88 |
| 8 | $213.27^{z}$ | $156.49^{yz}$ | $103.36^{xy}$ | $82.59^{x}$ | $68.19^{x}$ | 29.69 |

[a] Site x treatment interaction was detected ($P<0.10$)

[b] No input control

[c] Stubble clipped to 2.45 – 7.35 cm; conducted within 72h of fall trampling

[d] All sheep were muzzled while occupying a 111m² plot for 24hr (Fall+Spring 48h); Fall and Spring = 400 sheep d/ha, Fall+Spring = 800 sheep d/ha

[e] Sites located in Toole and Pondera counties

[w,x,y,z] Means within a row lacking a common superscript differ $P<0.10$

Change in biomass between TC and TCP did not differ ($P$=0.19) at site 8. At site 4, TC had a greater reduction ($P$<0.01) for change in biomass than TCP (Table 18; Appendix Table G). There was no difference ($P$=0.41) in the change at site 4 between TC and TF. There was a difference ($P$<0.02) between TC and TF in change in biomass at site 8, TC increased in biomass and TF decreased. There was more of a reduction ($P$<0.01) for change in biomass at site 4 for both TS and TFS than TC. In site 8, there was a difference ($P$<0.01) between TC and TS or TFS, TC increased and both TS and TFS decreased (Table 18; Appendix Table G).

Change in biomass at site 4 did not differ ($P$>0.33) between TS and TFS. There was more of a reduction ($P$=0.02) for TF than TCP, at site 4. At site 8, there was no difference ($P$=0.23) between TF and TCP (Table 18; Appendix Table G). There was no difference ($P$>0.11) between TCP and TS at either site. At site 8, there was a difference ($P$<0.01) between TCP and TFS, for change in biomass. Clipped increased and TFS decreased. Change did not differ ($P$=0.36) between TCP and TFS at site 4. Within the trample treatments, there were no differences ($P$>0.10) at either of the sites for change in biomass (Table 18; Appendix Table G).

Percent Biomass Remaining. The site by treatment interaction was significant ($P$<0.01; Table 18; Appendix Table G) for percent biomass remaining. Therefore, results are presented as the simple effects of treatment within location.

Control had a greater ($P$<0.01) percent biomass remaining than TCP at site 4. Percent biomass remaining between TC and TCP did not differ ($P$=0.19) at site 8 (Table 18; Appendix Table G). At site 4, there were no differences ($P$=0.52) between

TC and TF. Percent biomass remaining was greater ($P<0.01$) in TC than TF at site 8. Control had greater ($P<0.07$) percent biomass remaining in both sites compared to TS or TFS (Table 18; Appendix Table G).

Percent biomass remaining was greater ($P<0.01$) in TF than TCP, at site 4. At site 8, there were no differences ($P=0.23$) between TCP and TF. Percent biomass remaining was lower ($P<0.04$) in TCP than TS or TFS, at site 4. At site 8, TCP was greater ($P<0.10$) than TS and TFS (Table 18; Appendix Table G). Percent biomass remaining did not differ ($P>0.15$) among any of the trample treatments (Table 18; Appendix Table G).

Weeds

Grazing Versus Control and Tillage Experiment

Beginning Weed Frequencies. The site by treatment interaction was significant ($P<0.01$; Table 19; Appendix Table H) for beginning weed frequencies. Therefore, results are presented as the simple effects of treatment within location. Only 2000-2001 weed data was analyzed due to drought.

Ending Weed Frequencies. The site by treatment interaction was not significant ($P=0.15$; Table 20) for ending weed densities. Therefore, the main effects of treatment across sites are presented. Ending weed frequency was greater ($P<0.01$) in GC than GT. Control had greater ($P<0.01$) weed frequencies than GF, GS, or GFS (Table 20). Weed frequencies at the end of the experiment did not differ ($P=0.93$)

Table 19. Interaction[a] of site by treatment for beginning treatment and change in percent of weeds in control (GC)[b], tilled (GT)[c] fall (GF), spring (GS), and fall+spring (GFS) grazed[d] plots at 8 sites[e] in Montana, taken October 2000 and May 2001.

| | | | Grazed | | | |
|---|---|---|---|---|---|---|
| Site | Control | Tilled | Fall | Spring | Fall+Spring | SE |
| Beginning treatment | | | | | | |
| 1 | 22.0$^{x}$ | 21.0$^{x}$ | 18.3$^{x}$ | 85.0$^{y}$ | 20.25$^{x}$ | 2.06 |
| 2 | 23.8 | 26.3 | 24.8 | 26.3 | 27.5 | 2.46 |
| 3 | 17.5$^{x}$ | 23.8$^{y}$ | 22.5$^{y}$ | 21.3$^{xy}$ | 23.8$^{y}$ | 1.61 |
| 4 | 27.5 | 33.8 | 30.0 | 28.8 | 32.5 | 4.89 |
| Change, % | | | | | | |
| 1 | 69.3$^{w}$ | -11.0$^{x}$ | -10.8$^{x}$ | -85.0$^{y}$ | -20.3$^{z}$ | 2.75 |
| 2 | 60.0$^{x}$ | -19.5$^{y}$ | -20.3$^{y}$ | -26.3$^{yz}$ | -27.5$^{z}$ | 2.82 |
| 3 | 67.5$^{x}$ | -16.0$^{y}$ | -17.0$^{y}$ | -15.0$^{y}$ | -23.5$^{y}$ | 3.81 |
| 4 | 52.5$^{x}$ | -27.5$^{yz}$ | -16.0$^{z}$ | -28.3$^{yz}$ | -32.5$^{y}$ | 5.90 |

[a] Site x treatment interaction was detected ($P<0.01$)

[b] No input control

[c] Shallow tillage (20 cm) was conducted within 72h of fall grazing

[d] Sheep grazed 111m² plots for 24h (48h for Fall+Spring); Fall and Spring grazed at 400 sheep d/ha, Fall+Spring grazed at 800 sheep d/ha

[e] Sites located in Toole, Pondera, and Stillwater counties

[x,y,z] Means within a row lacking a common superscript differ $P<0.10$

Table 20. Ending treatment of weed percent in control **(GC)**[b], tilled **(GT)**[c] fall **(GF)**, spring **(GS)**, and fall+spring **(GFS)** grazed[d] plots at 4 combined sites[e] in Montana, taken October 2000 and May 2001.

| | | | Grazed | | | |
|---|---|---|---|---|---|---|
| | Control | Tilled | Fall | Spring | Fall+Spring | SE |
| Ending Treatment | 85.0[x] | 7.7[y] | 7.9[y] | 1.7[z] | 0.1[z] | 1.43 |

[a] No site x treatment interaction was detected ($P>0.15$)
[b] No input control
[c] Shallow tillage (20 cm) was conducted within 72h of fall grazing
[d] Sheep grazed 111m² plots for 24h (48h for Fall+Spring); Fall and Spring grazed at 400 sheep d/ha, Fall+Spring grazed at 800 sheep d/ha
[e] Sites located in Toole and Pondera, and Stillwater counties
[x,y,z] Means within a row lacking a common superscript differ $P<0.10$

between GT and GF. Till had higher ($P<0.01$) ending weed frequencies than GS or GFS (Table 20). There was no difference ($P=0.42$) between GS and GFS. Ending weed frequencies were higher ($P<0.01$) in GF treatments than GS or GFS (Table 20).

Percent Change in Weed Frequencies. The site by treatment interaction was significant ($P<0.01$; Table 19; Appendix Table H) for percent change in weed frequencies. Therefore, results are presented as the simple effects of treatment within site.

There was a difference ($P<0.01$) between GC and GT for percent change in weeds frequencies, weed frequencies increased in GC and decreased at in GT all four sites (Table 19; Appendix Table H). A difference ($P<0.01$) was detected between GC and all grazing treatments, GC increased in percent change in weed frequencies and GF, GS, and GFS decreased at all four sites (Table 19; Appendix Table H).

Percent change in weeds frequencies did not differ ($P>0.19$) at any of the four sites between GT and GF. At three out of the four sites, GT and GS did not differ ($P>0.11$). At site 1, GS had a greater reduction ($P<0.01$) in percent change in weed frequencies than GT (Table 19; Appendix Table H). At sites 1 and 2, percent change in weed frequencies were reduced more ($P<0.06$) in GFS than GT. Tilled and GFS did not differ ($P>0.18$) at sites 3 and 4 (Table 19; Appendix Table H).

At three sites, there were no differences ($P>0.15$) in percent change in weeds between GF and GS. At site 1, GS had more of a reduction ($P<0.01$) in percent change in weeds than GF (Table 19; Appendix Table H). There was more of a reduction ($P<0.09$) in GFS at three sites than GF. At site 3, there were no differences

($P$>0.25) between GF and GFS.. Percent change in weeds did not differ ($P$>0.14) at three sites between GS and GFS. At site 1, GS had more of a reduction ($P$<0.01) in weeds than GFS (Table 19; Appendix Table H).

Fall Burned Versus Control, Fall Grazed, and Tilled Experiment

Beginning Weed Frequencies. The site by treatment interaction was not significant ($P$=0.90) for beginning weed frequencies in burn treatment plots (Table 21). Therefore, main effect of treatment across sites is presented.

Ending Weed Frequencies. The site by treatment interaction was not significant ($P$=0.28) for ending weed frequencies (Table 21). Therefore, main effect of treatment across sites is presented.

Ending weed frequency was greater ($P$<0.01) in BC than BB (Table 21). Burn had a lower ($P$=0.03) ending weed frequencies than BT. Ending weed frequencies were greater ($P$=0.02) in BF than BB (Table 21)

Percent Change in Weed Frequencies. The site by treatment interaction was not significant ($P$=0.67; Table 21) for percent change in weeds. Therefore, main effects of treatment across sites are presented.

There was a difference ($P$<0.01) in the percent change of weeds between BC and BB, BC increased and BB decreased (Table 21). Burn had more of a reduction ($P$<0.08) in percent change than BT. There was more of a reduction in BB than BF ($P$=0.01; Table 21).

Table 21. Beginning treatment[a], ending treatment[a], and change[a] in weed percentage in control **(BC)**[b], tilled **(BT)**[c], burned **(BB)**[d], and fall grazed **(BF)**[e] plots at 4 combined sites[e] in Montana, taken October 2000 and May 2001.

| | Control | Tilled | Burned | Fall Grazed | SE |
|---|---|---|---|---|---|
| Beginning treatment | 22.7 | 26.2 | 26.7 | 23.9 | 1.68 |
| Ending treatment | 85.0$^{x}$ | 7.7$^{y}$ | 2.2$^{z}$ | 7.9$^{y}$ | 1.58 |
| Change, % | 62.3$^{x}$ | -18.5$^{y}$ | -24.5$^{z}$ | -16.0$^{y}$ | 2.19 |

[a] No site x treatment interaction was detected ($P>0.28$)
[b] No input control
[c] Shallow tillage (20 cm) was conducted within 72h of fall grazing
[d] Burning was conducted within 72h of fall grazing[e] Sheep grazed 111m² plots for 24h
[e] Sites located in Toole, Pondera, and Stillwater counties
[x,y] Means within a row lacking a common superscript differ $P<0.10$

Trample Versus Control and Clip

Only one site (site 4) was analyzed due to drought (Table 22). Ending weed frequencies and percent change in weed frequencies did not differ ($P>0.13$) among any treatment comparisons (Table 22; Appendix B) made in this experiment.

Discussion. Soil moisture is a major concern of Montana grain producers (Weise, 1985) Weeds and volunteer grain deplete soil moisture and nutrients (Greb, 1981). Stubble is needed in dryland grain production to trap snow and increase soil moisture (Brown, 1977). Therefore, grain producers want to reduce weed populations without decreasing stubble.

In our experiment, GT and GF were equivalent in their reduction of weeds and biomass. Ending samples were taken directly after the spring graze and it was expected that the spring grazed treatments would have less biomass than the fall treatments.

Tillage and GF seem to be comparable in their ability to manage weed populations. The most effective treatment evaluated was the GFS treatments. In the GFS treatments plots were grazed both in the fall and the spring, thus doubling the stocking rate. In years without drought it may be necessary to graze both fall and spring. Fallow grazing for weed management may depend on the type and quantity of weeds present to determine the timing of grazing and stocking rate. The NRCS recommendation for percent cover on clay loam soil is 25 to 30% (Lenssen, personal communication, 2003). Grazing would be tailored to each farm in order to stay within

Table 22. Beginning treatment[a], ending treatment, and change[a] in weed percentage for control (TC)[b], clipped (TCP)[c], fall (TF), spring (TS), and fall+spring (TSF) trampled[d] plots at 1 site[e] in Montana, taken October 2000 and May 2001.

| | | | Trampled | | | |
|---|---|---|---|---|---|---|
| | Control | Clipped | Fall | Spring | Fall+Spring | SE |
| Beginning Treatment | 27.5 | 25.0 | 27.5 | 28.0 | 26.25 | 4.28 |
| Ending Treatment | 80.0 | 75.0 | 67.5 | 85.5 | 80.5 | 6.67 |
| Change, % | 52.5 | 50.0 | 40.0 | 54.5 | 45.0 | 8.66 |

[a] No site x treatment interaction was detected ($P>0.28$)

[b] No input control

[c] Stubble clipped to 2 – 7 cm; conducted within 72h of fall trampling

[d] All sheep were muzzled while occupying a 111 m² plot for 24 hr (Fall+Spring 48h); Fall and Spring = 400 sheep d/ha, Fall+Spring = 800 sheep d/ha

[e] Sites located in Toole and Pondera counties

[x,y,z] Means within a row lacking a common superscript differ $P<0.10$

these guidelines. Trampling did not have an effect on biomass and weed populations. No differences were detected between any of the treatments.

# IMPLICATIONS

Sheep can be used as a tool in an integrated pest management system. They can be incorporated into wheat farming systems to both reduce WSS and weed populations without increasing soil compaction. Sheep grazing plus solid stem wheat and perhaps another management practice may greatly reduce WSS numbers. In addition to reducing WWS, producers will also receive some weed management. Sheep grazing may not be the answer to the WSS and weed problem in fallow but it could be a large piece to the puzzle.

More research is currently in progress. This project has expanded to a total farm grazing project. However, more research is still needed to compare sheep grazing with chemical fallow for weed management.

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# APPENDICIES

# APPENDIX A

## COMPARISONS OF TREATMENTS

Appendix Table A. Comparisons of treatments for beginning and ending wheat stem sawfly counts per 0.46 m of row in control **(GC)**[a], tilled **(GT)**[b], Fall grazed **(GF)** [c], spring grazed **(GS)** [c], and fall and spring combined grazed **(GFS)**[c] plots at 8 sites[d] in Montana, taken October 2000, May 2001, September 2001, and May 2002.

| Comparison | > | < | No Difference |
|---|---|---|---|
| Beginning treatment | 0 | 0 | 8 |
| GC versus GT | 0 | 0 | 8 |
| GC versus GF | 1 | 0 | 7 |
| GC versus GS | 0 | 0 | 8 |
| GC versus GFS | 0 | 0 | 8 |
| GT versus FG | 0 | 0 | 8 |
| GT versus GS | 3 | 0 | 5 |
| GT versus GFS | 0 | 1 | 7 |
| GF versus GS | 3 | 0 | 5 |
| GF versus GFS | 0 | 0 | 8 |
| GS versus GFS | 0 | 2 | 6 |
| Ending treatment | | | |
| GC versus GT | 1 | 0 | 7 |
| GC versus GF | 2 | 0 | 6 |
| GC versus GS | 3 | 0 | 5 |
| GC versus GFS | 4 | 0 | 4 |
| GT versus GF | 1 | 0 | 7 |
| GT versus GS | 3 | 0 | 5 |
| GT versus GFS | 3 | 0 | 5 |
| GF versus GS | 2 | 0 | 6 |
| GF versus GFS | 1 | 0 | 7 |
| GS versus GFS | 0 | 0 | 8 |

[a] No input control

[b] Shallow tillage (20 cm) was conducted within 72h of fall grazing[c] Sheep grazed 111m² plots for 24h (48h for Fall+Spring); Fall and Spring grazed 400 sheep d/ha, Fall+Spring grazed at 800 sheep d/ha

[d] Sites located in Toole, Pondera, and Stillwater counties

Appendix Table B. Comparisons of treatments for ending treatment wheat stem sawfly counts per 0.46 m of row in control **(TC)**[a], clipped **(TCP)**[b], and fall trampled **(TF)** [c], spring trampled **(TS)** [c], and fall and spring combined trampled **(TFS)**[c] plots at 2 sites[d] in Montana, taken October 2000 through May 2001 and September 2001 through May 2002.

| Comparison | > | < | No Difference |
|---|---|---|---|
| TC versus TCP | 0 | 0 | 2 |
| TC versus TF | 2 | 0 | 0 |
| TC versus TS | 1 | 0 | 1 |
| TC versus TFS | 2 | 0 | 0 |
| TCP versus TF | 2 | 0 | 0 |
| TCP versus TS | 1 | 0 | 1 |
| TCP versus TFS | 2 | 0 | 0 |
| TF versus TS | 0 | 1 | 1 |
| TF versus TFS | 0 | 0 | 2 |
| TS versus TFS | 2 | 0 | 0 |

[a] No input control

[b] Stubble clipped between 2 – 7cm; conducted within 72h of fall trampling

[c] All sheep were muzzled while occupying a 111m² plot for 24 hr (Fall+Spring 48h); Fall and Spring = 400 sheep d/ha, Fall+Spring = 800 sheep d/ha

[d] Sites located in Toole and Pondera counties

Appendix Table C. Comparison of treatments for beginning treatment, ending treatment and change in soil bulk density ($Mg/m^3$) in control (GC)[a], tilled (GT)[b], fall (GF), spring (GS), and fall and spring combined (GFS) grazed[c] treatments October 2000, May 2001, September 2001, and through May 2002 at sites[d] in Montana.

| Comparison | > | < | No Difference |
|---|---|---|---|
| Beginning treatment | | | |
| GC versus GT | 0 | 0 | 8 |
| GC versus GF | 0 | 0 | 8 |
| GC versus GS | 1 | 1 | 6 |
| GC versus GFS | 0 | 1 | 7 |
| GT versus GF | 1 | 0 | 7 |
| GT versus GS | 3 | 2 | 3 |
| GT versus GFS | 1 | 2 | 5 |
| GF versus GS | 0 | 1 | 7 |
| GF versus GFS | 0 | 2 | 6 |
| GS versus GFS | 1 | 3 | 4 |
| Ending treatment | | | |
| GC versus GT | 2 | 0 | 6 |
| GC versus GF | 2 | 0 | 6 |
| GC versus GS | 0 | 1 | 7 |
| GC versus GFS | 2 | 1 | 5 |
| GT versus GF | 1 | 1 | 6 |
| GT versus GS | 0 | 2 | 6 |
| GT versus GFS | 0 | 2 | 6 |
| GF versus GS | 0 | 2 | 6 |
| GF versus GFS | 0 | 1 | 7 |
| GS versus GFS | 2 | 1 | 5 |
| Change | | | |
| GC versus GT | 1 | 0 | 7 |
| GC versus GF | 1 | 0 | 7 |
| GC versus GS | 0 | 0 | 8 |
| GC versus GFS | 2 | 0 | 6 |
| GT versus GF | 1 | 1 | 6 |
| GT versus GS | 0 | 2 | 6 |
| GT versus GFS | 1 | 2 | 5 |
| GF versus GS | 1 | 2 | 5 |
| GF versus GFS | 1 | 0 | 7 |
| GS versus GFS | 2 | 0 | 6 |

[a] No input control

[b] Shallow tillage (20 cm) was conducted within 72h of fall grazing

[c] Sheep grazed 111$m^2$ plots for 24h (48h for Fall+Spring); Fall and Spring grazed at 400 sheep d/ha, Fall+Spring grazed at 800 sheep d/ha

[d] Sites located in Toole, Pondera, and Stillwater counties

Appendix Table D. Comparison of treatments for ending treatment and change in soil bulk density ($Mg/m^3$) in control **(BC)**[a], tilled **(BT)**[b], burned **(BB)**, and fall grazed **(BF)**[c] treatments October 2000, May 2001, September 2001, and May 2002 at 8 sites[d] in Montana.

| Comparison | > | < | No Difference |
|---|---|---|---|
| Ending Treatment | | | |
| BC versus BT | 2 | 0 | 4 |
| BC versus BB | 1 | 0 | 5 |
| BC versus BF | 1 | 1 | 4 |
| BT versus BB | 0 | 1 | 5 |
| BT versus BF | 0 | 2 | 4 |
| BB versus BF | 0 | 2 | 4 |
| Change | | | |
| BC versus BT | 1 | 0 | 5 |
| BC versus BB | 1 | 0 | 5 |
| BC versus BF | 1 | 0 | 5 |
| BT versus BB | 0 | 1 | 5 |
| BT versus BF | 1 | 1 | 4 |
| BB versus BF | 0 | 0 | 6 |

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

Appendix Table E. Comparison of treatments for beginning treatment, change in weight (g), percent change, and percent remaining of biomass in control **(GC)**[a], tilled **(GT)**[b], fall **(GF)**, spring **(GS)**, and fall and spring combined **(GFS)** grazed[c] plots at 8 sites[d] in Montana, taken October 2000, May 2001, September 2001, and May 2002.

| Comparison | > | < | No Difference |
|---|---|---|---|
| Beginning treatment | | | |
| GC versus GT | 0 | 0 | 8 |
| GC versus GF | 0 | 0 | 8 |
| GC versus GS | 0 | 1 | 7 |
| GC versus GFS | 0 | 0 | 8 |
| GT versus GF | 0 | 0 | 8 |
| GT versus GS | 2 | 1 | 5 |
| GT versus GFS | 1 | 0 | 7 |
| GF versus GS | 1 | 1 | 6 |
| GF versus GFS | 0 | 0 | 8 |
| GS versus GFS | 1 | 1 | 6 |
| Change, g | | | |
| GC versus GT | 6 | 0 | 2 |
| GC versus GF | 6 | 0 | 2 |
| GC versus GS | 5 | 0 | 3 |
| GC versus GFS | 7 | 0 | 1 |
| GT versus GF | 0 | 0 | 8 |
| GT versus GS | 2 | 2 | 4 |
| GT versus GFS | 3 | 0 | 5 |
| GF versus GS | 1 | 1 | 6 |
| GF versus GFS | 1 | 0 | 7 |
| GS versus GFS | 3 | 0 | 5 |
| Change, % | | | |
| GC versus GT | 7 | 0 | 1 |
| GC versus GF | 6 | 0 | 2 |
| GC versus GS | 6 | 0 | 2 |
| GC versus GFS | 8 | 0 | 0 |
| GT versus GF | 1 | 0 | 7 |
| GT versus GS | 2 | 1 | 5 |
| GT versus GFS | 5 | 0 | 3 |
| GF versus GS | 1 | 1 | 6 |
| GF versus GFS | 3 | 0 | 5 |
| GS versus GFS | 4 | 0 | 4 |

[a] No input control

[b] Shallow tillage (20 cm) was conducted within 72h of fall grazing

[c] Sheep grazed 111m² plots for 24h (48h for Fall+Spring); Fall and Spring grazed at 400 sheep d/ha, Fall+Spring grazed at 800 sheep d/ha

[d] Sites located in Toole, Pondera, and Stillwater counties

Appendix Table E (cont). Comparison of treatments for pre-fall treatment, change in weight (g), percent change, and percent remaining of biomass in control **(GC)**[a], tilled **(GT)**[b], fall **(GF)**, spring **(GS)**, and fall and spring combined **(GFS)** grazed[c] plots at 8 sites[d] in Montana, taken October 2000, May 2001, September 2001, and May 2002.

| Comparison | > | < | No Difference |
|---|---|---|---|
| Remaining, % | | | |
| GC versus GT | 7 | 0 | 1 |
| GC versus GF | 8 | 0 | 0 |
| GC versus GS | 6 | 0 | 2 |
| GC versus GFS | 8 | 0 | 0 |
| GT versus GF | 1 | 0 | 7 |
| GT versus GS | 2 | 3 | 3 |
| GT versus GFS | 5 | 0 | 3 |
| GF versus GS | 1 | 1 | 6 |
| GF versus GFS | 3 | 0 | 5 |
| GS versus GFS | 4 | 0 | 4 |

[a] No input control

[b] Shallow tillage (20 cm) was conducted within 72h of fall grazing

[c] Sheep grazed 111m² plots for 24h (48h for Fall+Spring); Fall and Spring grazed at 400 sheep d/ha, Fall+Spring grazed at 800 sheep d/ha

[d] Sites located in Toole, Pondera, and Stillwater counties

Appendix Table F. Comparison of treatments for change in weight (g) and percent remaining of biomass in control **(BC)**[a], tilled **(BT)**[b], burned **(BB)**[c] and fall grazed **(BF)**[d] plots at 8 sites[e] in Montana, taken October 2000, May 2001, September 2001, and May 2002.

| Comparison | > | < | No Difference |
|---|---|---|---|
| Change, g | | | |
| BC versus BT | 5 | 0 | 1 |
| BC versus BB | 5 | 0 | 1 |
| BC versus BF | 5 | 0 | 1 |
| BT versus BB | 0 | 1 | 5 |
| BT versus BF | 0 | 0 | 6 |
| BB versus BF | 1 | 1 | 4 |
| Remaining, % | | | |
| BC versus BT | 5 | 0 | 1 |
| BC versus BB | 5 | 0 | 1 |
| BC versus BF | 5 | 0 | 1 |
| BT versus BB | 0 | 1 | 5 |
| BT versus BF | 0 | 0 | 6 |
| BB versus BF | 1 | 1 | 4 |

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

Appendix Table G. Comparison of treatments for ending treatment, change in weight (g), change in percent, and change in percent remaining of biomass in control (TC)[b], clipped (TCP)[c], fall (TF), spring (TS) and fall and spring combined (TFS) trampled[d] plots at 2 sites[e] in Montana, taken October 2000, May 2001, September 2001, and May 2002.

| Comparison | > | < | No Difference |
|---|---|---|---|
| Ending treatment | | | |
| TC versus TCP | 1 | 0 | 1 |
| TC versus FT | 1 | 0 | 1 |
| TC versus ST | 1 | 0 | 1 |
| TC versus FST | 1 | 0 | 1 |
| TC versus FT | 1 | 1 | 0 |
| TCP versus ST | 0 | 1 | 1 |
| TCP versus FST | 1 | 1 | 0 |
| TF versus ST | 0 | 0 | 2 |
| TF versus FST | 0 | 0 | 2 |
| TS versus FST | 0 | 0 | 2 |
| Change, g | | | |
| TC versus TCP | 1 | 1 | 0 |
| TC versus TF | 1 | 0 | 1 |
| TC versus TS | 2 | 0 | 0 |
| TC versus TFS | 1 | 0 | 1 |
| TCP versus TF | 1 | 1 | 0 |
| TCP versus TS | 1 | 0 | 1 |
| TCP versus TFS | 1 | 0 | 1 |
| TF versus TS | 1 | 0 | 1 |
| TF versus TFS | 0 | 0 | 2 |
| TS versus TFS | 0 | 0 | 2 |
| Change, % | | | |
| TC versus TCP | 2 | 0 | 0 |
| TC versus TF | 1 | 0 | 1 |
| TC versus TS | 2 | 0 | 0 |
| TC versus TFS | 2 | 0 | 0 |
| TCP versus TF | 1 | 1 | 0 |
| TCP versus TS | 1 | 1 | 0 |
| TCP versus TFS | 2 | 1 | 0 |
| TF versus TS | 2 | 0 | 0 |
| TF versus TFS | 2 | 0 | 0 |
| TS versus TFS | 0 | 0 | 2 |

[a] No input control

[b] Stubble clipped between 2 – 7cm; conducted within 72h of fall trampling

[c] All sheep were muzzled while occupying a 111m² plot for 24 hr (Fall+Spring 48h); Fall and Spring = 400 sheep d/ha, Fall+Spring = 800 sheep d/ha

[d] Sites located in Toole and Pondera counties

Appendix Table G (cont). Comparison of treatments for post-spring treatment, change in weight (g), change in percent, and change in percent remaining f biomass in control **(TC)**[b], clipped **(TCP)**[c], fall **(TF)**, spring **(TS)** and fall and spring combined **(TFS)** trampled[d] plots at 2 sites[e] in Montana, taken October 2000, May 2001, September 2001, and May 2002.

| Comparison | > | < | No Difference |
|---|---|---|---|
| Remaining, % | | | |
| TC versus TCP | 1 | 0 | 1 |
| TC versus TF | 1 | 0 | 1 |
| TC versus TS | 2 | 0 | 0 |
| TC versus TFS | 2 | 0 | 0 |
| TCP versus TF | 0 | 1 | 1 |
| TCP versus TS | 1 | 1 | 0 |
| TCP versus TFS | 1 | 1 | 0 |
| TF versus TS | 0 | 0 | 2 |
| TF versus TFS | 0 | 0 | 2 |
| TS versus TFS | 0 | 0 | 2 |

[a] No input control

[b] Stubble clipped between 2 – 7cm; conducted within 72h of fall trampling

[c] All sheep were muzzled while occupying a 111m² plot for 24 hr (Fall+Spring 48h); Fall and Spring = 400 sheep d/ha, Fall+Spring = 800 sheep d/ha

[d] Sites located in Toole and Pondera counties

Appendix Table H. Comparisons of treatments for beginning treatment and change in percent of weeds in control (GC)[a], tilled (GT)[b] fall (FG), spring (SG), and fall and spring combined (GFS) grazed[c] plots at 8 sites[d] in Montana, taken October 2000 and May 2001.

| Comparison | > | < | No Difference |
|---|---|---|---|
| Beginning treatment | | | |
| GC versus GT | 0 | 1 | 3 |
| GC versus GF | 0 | 1 | 3 |
| GC versus GS | 0 | 1 | 3 |
| GC versus GFS | 0 | 1 | 3 |
| GT versus GF | 0 | 0 | 4 |
| GT versus GS | 0 | 1 | 3 |
| GT versus GFS | 0 | 0 | 4 |
| GF versus GS | 0 | 1 | 3 |
| GF versus GFS | 0 | 0 | 4 |
| GS versus GFS | 1 | 0 | 3 |
| Change, % | | | |
| GC versus GT | 4 | 0 | 0 |
| GC versus GF | 4 | 0 | 0 |
| GC versus GS | 4 | 0 | 0 |
| GC versus GFS | 4 | 0 | 0 |
| GT versus GF | 0 | 0 | 4 |
| GT versus GS | 1 | 0 | 3 |
| GT versus GFS | 2 | 0 | 2 |
| GF versus GS | 1 | 0 | 3 |
| GF versus GFS | 3 | 0 | 1 |
| GS versus GFS | 0 | 1 | 3 |

[a] No input control
[b] Shallow tillage (20 cm) was conducted within 72h of fall grazing
[c] Sheep grazed 111m² plots for 24h (48h for Fall+Spring); Fall and Spring grazed at 400 sheep d/ha, Fall+Spring grazed at 800 sheep d/ha
[d] Sites located in Toole, Pondera, and Stillwater counties

# APPENDIX B

# OUTLINE OF RESULTS

# OUTLINE OF RESULTS

## I. Wheat Stem Sawfly

### A. Grazing Versus Control and Tillage Experiment

1. Beginning WSS Larval Numbers. A site by treatment interaction was detected ($P<0.01$) among treatments (Table 4; Appendix Table A). These differences are not a result of treatments, but rather the inherent variability in WSS larval population densities (Goosey, 1999).
2. Ending WSS Larval Numbers. A site by treatment interaction ($P<0.01$) was detected for the number of WSS larvae at the end of the study period (Table 4; Appendix Table A). Therefore, results are presented as the simple effects of treatment within location.
   a. GC versus GT . At the end of the study, GC and GT did not differ ($P=0.14$) in WSS live larvae counts at seven sites (Table 4; Appendix Table A). At one site, ending live WSS numbers were greater ($P=0.04$) for GC than GT.
   b. GC versus Graze. Ending live larval WSS numbers were greater ($P<0.04$) for GC at two, three, and four sites than GF, GS, and GFS, respectively. There were no differences ($P>0.14$) at the end of the study between GC, GF, GS, and GFS at the remaining sites (Table 4; Appendix Table A).
   c. GT versus Graze. When comparing GT to GF, GS, or GFS, GT had a greater ($P<0.06$) ending live larvae numbers at one, three, and three sites than GF, GS, or GFS, respectively. At the end of the study, there were no other

differences ($P>0.14$) between GT and any of the grazing treatments (Table 4; Appendix Table A).

d. Graze. At the end of the study, grazing treatments did not differ ($P>0.18$) at six, seven and eight study sites between GF versus GS, GF versus GFS, and GS versus GFS, respectively. At two sites at the end of the study, GF had greater ($P<0.05$) ending live larvae numbers than GS. At one site, GS had greater ($P=0.01$) ending live larvae than GFS (Table 4; Appendix Table A).

3. Change in WSS Larval Numbers. There was no site by treatment interaction ($P=0.37$), for change in the number of WSS live larvae. Therefore, the main effects of treatment across sites are presented (Table 5).

a. GC versus GT. Control did not differ ($P=0.41$) from GT for change in WSS larval numbers (Table 5).

b. GC versus Graze. No difference ($P=0.54$) was detected between GC and GS in change in WSS larval numbers. There was a greater reduction ($P<0.01$) of larvae numbers in GF and GFS than GC (Table 5).

c. GT versus Graze. There was no difference ($P=0.82$) in change in WSS larval numbers between GT and GS. Fall grazed and GFS had greater reductions ($P<0.02$) in change of larval numbers than GT (Table 5).

d. Graze. Change in larval numbers did not differ ($P=0.11$) between GF and GFS. Spring grazed had less reduction ($P<0.01$) of larvae numbers than both GF and GFS (Table 5).

4. Percent WSS Mortality. No site by treatment interaction was detected ($P=0.99$; Table

a. GC versus GT. No difference ($P$=0.55) was detected between GC and GT for percent WSS mortality (Table 5).

b. GC versus Graze. Control had a lower ($P$<0.01) percent mortality than GF, GS, and FS (Table 5).

c. GT versus Graze. All grazing treatments had a higher ($P$>0.01) percent mortality than GT.

d. Graze. The GFS treatment had a higher ($P$<0.04) percent mortality than either GF or GS. No difference ($P$=0.72) was detected in percent mortality between GF and GS (Table 5).

B. Fall Burned Versus Control, Fall Grazed, and Tilled Experiment

1. Beginning WSS Larval Numbers. No site by treatment interaction ($P$=0.97) was detected for beginning WSS live larval numbers (Table 6). Therefore, the main effect of treatment across site is presented.

2. Ending WSS Larval Numbers . No site by treatment interaction ($P$=0. 23) was detected for ending WSS live larval numbers (Table 6). Therefore the main effect of treatment across sites is presented.

a. BC versus BB. Live larvae numbers at the end of the study did not differ ($P$=0.34) between BC and BB (Table 6).

b. BB versus BT. Live larvae numbers at the end of the study did not differ ($P$=0.72) between BB and BT (Table 6).

c. BB versus BF. Wheat stem sawfly live larvae numbers at the end of the study did not differ ($P$=0.12) between BB and BF (Table 6).

3. Change in WSS Larval Numbers. No site by treatment interaction ($P$=0.95) was detected for change in live WSS larval numbers (Table 6). Therefore, the main effect of treatment across sites is presented.

a. BC versus BB. Change in larvae number did not differ ($P$=0.65) between BC and BB (Table 6).

b. BB versus BT. Change from beginning the beginning to the ending of the experiment in WSS live larvae numbers did not differ ($P$=0.75) between BB and BT (Table 6).

c. BB versus BF. Fall grazed had greater reduction ($P$=0.01) in WSS larvae numbers over the course of the study than BB (Table 6).

4. Percent WSS Mortality. No site by treatment interaction ($P$>0.94) was detected (Table 6) for percent WSS percent mortality. Therefore, the main effect of treatment across sites is presented.

a. BC versus BB. Percent mortality did not differ ($P$=0.53) between BC and BB (Table 6).

b. BB versus BT. Percent mortality did not differ ($P$=0.39) between BB and BT (Table 6).

c. BB versus BF. Fall grazed had a higher ($P$=0.05) percent mortality than BB (Table 6).

C. Trample Versus Control and Clip Experiment.

No site by treatment interaction ($P>0.90$) was detected prior to treatment imposition for live WSS larval numbers in the trample treatments (Table 7). Therefore, the main effect of treatment across sites is presented.

1. Beginning WSS Larval Numbers. No site by treatment interaction ($P>0.90$) was detected for beginning WSS live larval numbers (Table 7). Therefore, the main effect of treatment across site is presented.

2. Ending WSS Larval Numbers. A site by treatment interaction was detected ($P=0.02$) for ending live larval numbers. Therefore the treatments are presented as the simple effects of treatment within location (Table 8; Appendix Table B).

a. TC versus TCP. Ending WSS live larval numbers did not differ ($P>0.77$) between TC and TCP (Table 8; Appendix Table B).

b. TC versus Trample. Control plots had more ($P<0.06$) WSS live larvae at the end of the study than TF or TFS at both sites. Control had a greater ($P=0.05$) amount of WSS live larvae than TS at site 4, but did not differ at site 8 (Table 8; Appendix Table B).

c. TCP versus Trample. The TCP treatment had more ($P<0.08$) live larvae at both sites than TF and TFS. At site 4, TCP was greater ($P=0.03$) than TS and at site 8 there was no difference ($P=0.87$) in ending larvae numbers between TCP and TS (Table 8; Appendix Table B).

d. Trample. No difference ($P>0.12$) was detected between TF and TFS at either site. There was no difference ($P=0.70$) between TF and TS at site 4. At site

8, TS has more ($P$=0.01) larvae than TF. The TS plots had more ($P$<0.06) larvae than TFS at both sites (Table 8; Appendix Table B).

3. Change in WSS Larval Numbers. No site by treatment interaction ($P$>0.90) was detected for change in live larvae (Table 7). Therefore, the main effect of treatment across sites is presented.

a. TC versus TCP. No difference was detected from the beginning to the end of the experiment ($P$=0.74) for change between TC and TCP (Table 7).

b. TC versus Trample. No differences were detected ($P$=0.66) for change between TC and TF. The reduction ($P$<0.07) in live larvae was greater in TS and TFS than TC (Table 7).

c. TCP versus Trample . No difference was detected ($P$>0.16) between TCP and TF or TS. There was a greater reduction ($P$=0.01) in TFS compared to TCP for live larvae (Table 7).

d. Trample. No differences were found in live larvae between TS when compared to TFS or TS. There was a greater reduction ($P$=0.01) in TFS compared to TFS (Table 7).

4. Percent WSS Mortality. No site by treatment interaction ($P$>0.90) was detected for percent mortality (Table 7). Therefore, the main effect of treatment across sites is presented.

a. TC versus TCP. No difference ($P$=0.78) in percent mortality was detected between TC and TCP (Table 7).

b. TC versus Trample. There was no difference ($P$=0.15) detected between TC and TF. The TFS treatment had a higher ($P$<0.01) percent mortality than TC. Spring trample had a higher ($P$<0.09) percent mortality than TC (Table 7).

c. TCP versus Trample. There were no differences ($P$>0.18) in percent mortality when comparing TCP with TF and TS. Percent mortality was greater in TFS than TCP (Table 7).

d. Trample. The TFS trample treatment had a higher ($P$<0.01) percent mortality when compared to TF and TS. There was no difference ($P$=0.79) detected between TF and TS for percent mortality (Table 7).

## II. Soil Bulk Density

### A. Grazing Versus Control and Tillage Experiment

1. Beginning Bulk Density. A site by treatment interaction ($P$<0.01) was detected (Table 9; Appendix Table C). These differences are due to the inherent variability in soils at the different sites (Table 3).

2. Ending Bulk Density. A site by treatment interaction was detected ($P$<0.01). Therefore, the results are presented as the simple effects of treatment within location (Table 9; Appendix Table C).

a. GC versus GT. At the end of the study, no differences ($P$>0.55) were detected at six sites between GC and GT. At the remaining two sites bulk density was greater ($P$<0.05) in GC than GT (Table 9; Appendix Table C).

b. GC versus Graze. At the end of the study soil bulk density did not differ ($P$>0.22) between GC and GF at six of the eight study sites. At two sites, soil bulk density was greater ($P$<0.01) in GC than GF. There were no differences ($P$>0.40) at the end of the study in soil bulk density between GC and GS at seven sites (Table 9; Appendix Table C). At one site, soil bulk density was greater ($P$=0.05) in the GS treatment than the GC treatment at the end of the study. Soil bulk density did not differ (P>0.33) between GC and GFS at five sites, at the end of the study. At site 2, GC had less ($P$=0.04) soil bulk density than GFS. The GC treatment had greater ($P$=0.08) bulk density at sites 6 and 8 than GFS at the end of the study (Table 9; Appendix Table C).

c. GT versus Graze. At the end of the study at six out of eight sites, soil bulk density did not differ ($P$>0.30) between GT and GF. At one site, GT ending soil bulk density was greater ($P$=0.02) than GF. At the other sites, GF was greater ($P$<0.01). There was no difference ($P$>0.14) between GT and GS at six sites and at two sites GS was greater ($P$=0.07). In GT versus GFS, there were no differences ($P$>0.28) at six sites. Fall and spring combined graze was greater ($P$<0.03) at two sites than GT (Table 9; Appendix Table C).

d. Graze. At the end of the study, when comparing the grazing treatments among each other, GF versus GS and GFS there were no differences ($P$>0.11) in soil bulk density at six and seven sites, respectively. At five sites, there were no differences ($P$>0.22) in bulk density between GS and GFS at the end of the study. At two sites GS soil bulk density was greater ($P$<0.09) than both

GF and GFS. Soil bulk density was lower ($P<0.06$) in GF, at one site, than GFS, at the end of the study (Table 9; Appendix Table C).

3. Change in Bulk Density. A site by treatment interaction was detected ($P<0.01$). Therefore, the results are presented as the simple effects of treatment within location (Table 9; Appendix Table C).

a. GC versus GT. At seven out of eight sites there were no differences in change of soil bulk density ($P>0.11$) between GC and GT. At one site GT and GC differed ($P<0.01$) there was a reduction in GT and an increase in GC (Table 9; Appendix Table C).

b. GC versus Graze. There were no differences ($P>0.17$) detected in soil bulk density change between GC and GF at seven sites. There was a difference ($P<0.01$) at one site bulk density increased in GC and decreased in GF. Soil bulk density change did not differ ($P>0.12$) at any of the eight sites between GC versus GS. In the comparison of GC and GFS, at six sites there were no differences ($P>0.16$) for soil bulk density change (Table 9; Appendix Table C). At two sites GC and GFS differed ($P<0.03$), soil bulk density increased in GC and decreased in GFS (Table 9; Appendix Table C).

c. GT versus Graze. Soil bulk density change at six sites, did not differ ($P>0.12$) between GT and GF. At the other two sites results for soil bulk density change were mixed, at site 6, GT had a greater ($P=0.03$) reduction and at site 8, GF had a greater reduction ($P=0.03$). When comparing GT versus GS, at six sites there were no differences ($P>0.22$) in soil bulk density change (Table

9; Appendix Table C). Spring graze and GT differed ($P<0.03$) at two sites soil bulk density increased in GS and decreased in GT. For GT to GSF, at five sites there were no differences ($P>0.28$) in soil bulk density change. At site 5 there was a difference ($P<0.10$) between GT and GFS, GT soil density decreased and GFS increased. At site 6 there was a greater reduction in soil bulk density for GT than GFS ($P<0.10$). Tilled and GFS differed ($P=0.02$) at site 7, soil bulk density increased in GT and decreased in GFS (Table 9; Appendix Table C).

d. Graze. Soil bulk density change results were mixed among grazing treatments. In GF versus GS, at five sites there were no differences ($P>0.18$) in soil bulk density change. At site 1, GF soil bulk density change was increased more ($P=0.10$) than GS. Fall grazed and GS differed ($P<0.01$) at sites 6 and 8, GF soil bulk density was decreased and in GS it increased. Comparing GF with GFS, at seven sites there were no differences ($P>0.10$) in soil bulk density change. At site 1, GF soil bulk density change was increased ($P<0.03$) and in GFS it did not change. At six sites, there were no differences ($P>0.20$) when comparing soil bulk density change of GS to GFS. At sites 6 and 8, GS soil bulk density increased in GS and decreased in GFS ($P<0.08$;Table 9; Appendix Table C).

B. Fall Burned Versus Control, Fall Grazed, and Tilled Experiment

1. Beginning Bulk Density. No site by treatment interaction was detected ($P$=0.68; Table 10). Soil bulk density in beginning was not due to treatment imposition. It was due to the inherent variation within the soil at the treatment sites (Table 3).

2. Ending bulk density. A site by treatment interaction was detected ($P$<0.01; Table 11; Appendix Table D). Therefore, the results are presented as the simple effects of treatment within location.

a. BC versus BB. At five of the six sites no differences were detected ($P$>0.36) in ending soil bulk density between BC and BB. At site 6, ending soil bulk density was greater ($P$<0.01) for BC than BB (Table 11; Appendix Table D).

b. BB versus BT. Ending soil bulk density did not differ ($P$>0.54) between BT and BB at five of the six sites. At site 6, BT had greater ($P$<0.01) ending soil bulk density than BB (Table 11; Appendix Table D).

c. BB versus BF. No differences ($P$>0.39) were detected in ending soil bulk density between BB and BF at four sites of the six sites. At site 6, BB had lower ($P$<0.06) and at site 8 a greater ending bulk density than BF (Table 11; Appendix Table D).

3. Change in Bulk Density. A site by treatment interaction was detected ($P$=0.03; Table 11; Appendix Table D). Therefore, the results are presented as the simple effects of treatment within location.

a. BC versus BB. No differences ($P$>0.20) were detected in soil bulk density change between BC and BB at five out of the six sites. At site 8, soil bulk

density increased in BC and decreased in BB ($P$=0.03; Table 11; Appendix Table D).

b. BB versus BT. Soil bulk density change did not differ ($P$>0.37) between BT and BB at five of the six sites. At site 6, BB and BT differed ($P$<0.02), soil bulk density increased in BB and decreased in BT (Table 11; Appendix Table D).

c. BB versus BF. There were no differences ($P$>0.19) in soil bulk density change at any of the six sites between BB and BF (Table 11; Appendix Table D).

C. Trample Versus Control and Clip Experiment.

1. Beginning Bulk Density. No Site by treatment interaction ($P$=0.91) was detected (Table 12). Differences in soil bulk density at the beginning were not due to treatment imposition. Rather, inherent variability in soil and soil moisture among the treatment sites (Table 3).

2. Ending Bulk Density. There was no site by treatment interaction ($P$=0.80) detected (Table 12). Therefore, the main effects of treatment across sites are presented.

a. TC versus TCP. Ending soil bulk density was greater ($P$<0.09) in TC than TCP (Table 12).

b. TC versus Trample. Ending soil bulk density did not differ ($P$>0.17) between trample treatments and TC. (Table 12)

a. TCP versus Trample.. Ending soil bulk density did not differ ($P$>0.47) among TF, TS, or TFS (Table 12).

b. Trample. No differences ($P$>0.67) were detected in ending soil bulk density among TF, TS, and TFS (Table 12).

3. Change in Bulk Density. No site by treatment interaction was detected ($P$=0.91; Table 12). Therefore, the main effects of treatment across sites is presented.

a. TC versus TCP. No difference was detected ($P$=0.75) for bulk density change between TC and TCP from the beginning to the end of the study (Table 12).

b. TC versus Trample. Bulk density change did not differ ($P$>0.13) between TC, and TF, TS, or TFS (Table 12).

c. TCP versus Trample. There were no differences ($P$>0.23) between TF, TS, TFS, and TCP (Table 12).

d. Trample. Soil bulk density change for TFS did not differ ($P$>0.14) from TF or TS. Soil bulk density increased in TS and decreased in TF ($P$=0.08; Table 12).

## III, VI. Biomass and Weeds

### III . Biomass

A. Grazing Versus Control and Tillage Experiment.

1. Beginning Biomass. A site by treatment interaction was detected ($P$<0.05) for beginning biomass (Table 13; Appendix Table E). Differences in beginning biomass are not a result of treatments, but rather the inherent variability in biomass densities.

2. Ending Biomass. No site by treatment interaction was detected ($P$=0.16; Table 14) for ending biomass. Therefore, the main effects of treatment across sites are presented.

a. GC versus GT. Control plots had a greater ($P<0.01$) amount of ending biomass than GT (Table 14).

b. GC versus Graze. Control plots had a greater ($P<0.01$) amount of ending biomass than any of the grazing treatments (Table 14).

c. GT versus Graze. No differences ($P>0.15$) were detected in ending biomass when GT was compared to GF or GS. Tilled plots had a greater ($P<0.01$) amount of ending biomass than GFS (Table 14).

d. Graze. No differences ($P=0.36$) in ending biomass were detected between GF and GS. Ending biomass was less ($P<0.03$) in GFS than GF and GS (Table 14).

3. Change in Biomass. A site by treatment interaction was detected for change in amount of biomass ($P<0.01$; Table 13; Appendix Table E). Therefore, the results are presented as the simple effects of treatment within location.

a. GC versus GT. Control had less reduction ($P<0.05$) in biomass at four sites than GT from the beginning to the end of the study. There was a difference ($P<0.02$) at two sites, change in biomass increased in GC and decreased in GT. At two sites there were no differences ($P>0.12$; Table 13; Appendix Table E).

b. GC versus Graze. Control had a less reduction than GF at three sites ($P<0.01$) At two sites GC and GF differed ($P<0.05$), GC increased and GF decreased. Control and GF were not different ($P>0.40$) at two sites for change in biomass. At three out of the eight sites, GC had less reduction ($P<0.01$) in

biomass than GS (Table 13; Appendix Table E). At two sites GC and GS differed ($P<0.06$), GC had an increase in biomass and GS a reduction. At three sites there were no differences ($P>0.17$) between GC and GS for change in biomass. At five out of eight sites biomass was reduced more ($P<0.03$) in GFS than GC. At two sites GC and GFS differed ($P<0.01$) biomass increased in GC and decreased in GFS. There was no difference ($P=0.34$) change in the amount of biomass between GC and GFS at one site (Table 13; Appendix Table E).

c. GT versus Graze. The change in biomass did not differ ($P>0.10$) between GT and GF at all eight sites from the beginning to the end of the experiment. Results were mixed for change in biomass comparing GT with GS. At four sites there were no differences ($P>0.20$) in change, at two GT more of an increase ($P<0.05$) in biomass than GS and at two sites GS has more of an increase ($P<0.06$) in biomass (Table 13; Appendix Table E). At five sites, there were no differences in change of biomass ($P>0.12$) between GT and GFS. At three sites, GFS had a more of a reduction ($P<0.08$) for change in biomass than GT (Table 13; Appendix Table E).

e. Graze. When comparing the amount of biomass in grazing treatments, in GF to GS at six sites there were no differences ($P>0.12$). There was a difference ($P<0.01$) at site 1, GF had a greater reduction in biomass in GS than GF (Table 13; Appendix Table E). At site 3, there was a greater reduction ($P=0.04$) in biomass in GS than GF. At seven out of the eight sites, there

were no differences ($P>0.10$) between GF and GFS in the change of biomass. There was a greater reduction ($P<0.10$) for change in biomass in GFS than GF, at site 3. Comparing change in biomass between GS and GFS, at five sites there were no differences ($P>0.11$). At three sites, GSF had less of a reduction ($P<0.06$; Table 13; Appendix Table E) than GS.

4. Percent Biomass Remaining. A site by treatment interaction was detected ($P<0.01$; Table 13; Appendix Table E) for percent biomass remaining. Therefore, the results are presented as the simple effects of treatment within location.

a. GC versus GT. At seven out of eight sites GC had a higher ($P<0.04$) percent biomass remaining than GT. At site 3, there was no difference ($P=0.18$) between GC and GT for percent biomass remaining (Table 13; Appendix Table E).

b. GC versus Graze. Control had a higher ($P<0.04$) percent biomass remaining than GF and GS at six sites. At two sites, there were no differences ($P>0.11$) in percent biomass remaining between GC and GF or GS. At all eight sites GC had a higher ($P<0.01$) percent biomass remaining than GFS (Table 13; Appendix Table E).

c. GT versus Graze. At seven out of eight sites, there were no differences ($P>0.22$) in percent biomass remaining when GT was compared with GF. At one site, GT had greater ($P<0.07$) percent biomass remaining than GF. At two sites GT had greater ($P<0.04$) percent biomass remaining than GS, and at one site it was less ($P=0.10$). At five sites GT had a higher ($P<0.06$) percent

biomass remaining than GFS and at three sites there were no differences ($P$>0.19) between GT and GFS in percent biomass remaining (Table 13; Appendix Table E).

d. Graze. Percent biomass remaining did not differ ($P$>0.35) between GF and GS at six sites. At site 3, GF had a greater ($P$=0.08) percent biomass remaining than GS. At site 6, GS had a greater ($P$=0.07) percent biomass remaining than GF. Comparing GFS with GF at five sites there were no differences ($P$>0.23) in percent biomass remaining. At three sites; GF had a greater ($P$<0.02) percent biomass remaining than GFS. At four sites, there were no differences ($P$>0.27) between GFS and GS. The GS treatment had a greater ($P$<0.08) percent remaining than GFS at four sites (Table 13; Appendix Table E).

B. Fall Burned Versus Control, Fall Grazed, and Tilled Experiment

1. Beginning Biomass. No site by treatment interaction ($P$=0.72) was detected (Table 15) in beginning biomass. Therefore, the main effects of treatment across sites are presented.

2. Ending Biomass. There was no site by treatment interaction detected ($P$=0.13; Table 15) for ending amount of biomass. Therefore, the main effect of treatment across sites is presented.

a. BC versus BB. Control had greater ($P$<0.01) amount of ending biomass than BB (Table 15).

b. BB versus BT. There was no difference ($P$=0.76) in ending amount of biomass between BB and BT (Table 15).

c. BB versus BF. Ending biomass was not different ($P$=0.89) between BB and BF (Table 15).

3. Change in Biomass. No site by treatment interaction was detected ($P$=0.13; Table 15) for change in the amount of biomass in burn treatment sites. Therefore, the main effects of treatment across sites are presented.

a. BC versus BB. Control and BB differed ($P$<0.01), had an increase in the amount of biomass and BB decreased in the amount of biomass (Table 15).

b. BB versus BT. The change in amount of biomass did not differ ($P$=0.27) between BB and BT (Table 15).

c. BB versus BF. No differences were detected ($P$=0.54) in the change in the amount of biomass between BB and BF (Table 15).

4. Percent Biomass Remaining. A site by treatment interaction was detected ($P$=0.10; Table 16; Appendix Table F) for percent biomass remaining. Therefore, results are presented as the simple effects of treatment within location.

a. BC versus BB. At five out of six sites BC had a greater ($P$<0.06) percent biomass remaining than BB. At site 7, there was no difference ($P$=0.66) in percent biomass remaining (Table 16; Appendix Table F).

b. BB versus BT. There was no difference ($P$>0.15) in percent biomass remaining between BT and BB at five sites. The BB treatment had greater ($P$=0.01) percent biomass remaining at site 7 than BT (Table 16; Appendix Table F).

c. BB versus BF. Percent biomass remaining results were mixed when comparing BB with BF. At four out of the six sites there were no differences ($P$>0.15) between BB and BF. At site 7, BB had greater ($P$=0.03) percent biomass remaining than BF. At site 3, BF had greater ($P$=0.09) percent biomass remaining than BB (Table 16; Appendix Table F).

C. Trample Versus Control and Clip Experiment.

1. Beginning Biomass No site by treatment interaction was detected ($P$=0.13; Table 17) for beginning biomass. Therefore, the main effects of treatment across sites are presented.

2. Ending Biomass. A site by treatment interaction was detected ($P$<0.01) for the amount of ending biomass (Table 18; Appendix Table G). Therefore, results are presented as the simple effects of treatment within location.

a. TC versus TCP: Ending biomass was greater ($P$<0.01) in TC than TCP, at site 4. At site 8, there was no difference ($P$=0.28) between TC and TCP (Table 18; Appendix Table G).

b. TC versus Trample. Control had a greater ($P$<0.01) amount of ending biomass at site 8, than TF, TS or TFS. At site 4, there was no difference ($P$>0.65) between TC and TF, TS or TFS (Table 18; Appendix Table G).

c. TCP versus Trample. The ending amount of biomass was greater ($P$<0.01) in TF, TS, and TFS than TCP at site 4. At site 8, there was no difference ($P$=0.11) in ending biomass between TCP and TS. Ending biomass was

greater ($P<0.01$) in TCP than TF or TFS at site 8 (Table 18; Appendix Table G).

d. Trample. There were no differences ($P>0.23$) in ending biomass among the trample treatments (Table 18; Appendix Table G).

3. Change in Biomass. A site by treatment interaction was detected ($P=0.09$; Table 18; Appendix Table G) for the change in the amount of biomass. Therefore, results are presented as the simple effects of treatment within location.

a. TC versus TCP. Change in the amount of biomass between TC and TCP did not differ ($P=0.19$) at site 8. At site 4, TC had a greater reduction ($P<0.01$) in amount of biomass than TCP (Table 18; Appendix Table G).

b. TC versus Trample. There was no difference ($P=0.41$) in the change in amount of biomass at site 4 between TC and TF. There was a difference ($P<0.02$) between TC and TF in change in amount of biomass at site 8, TC increased in biomass and TF decreased. There was more of a reduction ($P<0.01$) in biomass at site 4 for both TS and TFS than TC. In site 8, ther was a difference ($P<0.01$) between TC and TS or TFS, TC increased and both TS and TFS decreased in the amount of biomass (Table 18; Appendix Table G).

c. TCP versus Trample. Change in the amount of biomass at site 4 did not differ ($P>0.33$) between TS and TFS. There was more of a reduction ($P=0.02$) in biomass for TF than TCP, at site 4. At site 8, there was no difference ($P=0.23$) between TF and TCP (Table 18; Appendix Table G). There was no difference ($P>0.11$) between TCP and TS at either site. At site 8, there was a

difference ($P<0.01$) between TCP and TFS, the amount of biomass increased in TCP and decreased in TFS. Change in the amount of biomass did not differ ($P=0.36$) between TCP and TFS at site 4 (Table 18; Appendix Table G).

d. Trample. Within the trample treatments, there were no differences ($P>0.10$) at either of the sites for change in the amount of biomass (Table 18; Appendix Table G).

4. Percent Biomass Remaining. A site by treatment interaction was detected ($P<0.01$; Table 18; Appendix Table G) for percent biomass remaining. Therefore, results are presented as the simple effects of treatment within location.

a. TC versus TCP. Control had a greater ($P<0.01$) percent biomass remaining than TCP at site 4. Percent biomass remaining between TC and TCP did not differ ($P=0.19$) at site 8 (Table 18; Appendix Table G).

b. TC versus Trample. At site 4, percent biomass remaining did not differ ($P=0.52$) between TC and TF. Percent biomass remaining was greater ($P<0.01$) in TC than TF at site 8. Control had greater ($P<0.07$) percent biomass remaining in both sites compared to TS or TFS (Table 18; Appendix Table G).

c. TCP versus Trample. Percent biomass remaining was greater ($P<0.01$) in TF than TCP, at site 4. At site 8, percent biomass remaining did not differ ($P=0.23$) between TCP and TF. Percent biomass remaining was lower ($P<0.04$) in TCP than TS or TFS, at site 4. At site 8, TCP was greater ($P<0.10$) than TS and TFS (Table 18; Appendix Table G).

d. Trample. Percent biomass remaining did not differ ($P>0.15$) among any of the trample treatments (Table 18; Appendix Table G).

III. Weeds

A. Grazing Versus Control and Tillage Experiment

1. Beginning weed Frequencies. A site by treatment interaction was detected ($P<0.01$; Table 19; Appendix Table H) for beginning weed frequencies. These differences were not due to treatments imposed, but rather differences among weed species and population frequencies within sites. Only 2000-2001 weed data was analyzed due to drought.

2. Ending Weed Frequencies. No site by treatment interaction was detected ($P=0.15$; Table 20) for ending weed frequencies. Therefore, the main effects of treatment across sites are presented.

a. GC versus GT. Ending weed density was greater ($P<0.01$) in GC than GT.

b. GC versus Graze. Control had greater ($P<0.01$) weed frequencies than GF, GS, or GFS (Table 20).

c. GT versus Graze. Ending weed frequencies did not differ ($P=0.93$) between GT and GF. Till had higher ($P<0.01$) ending weed frequencies than GS or GFS (Table 20).

d. Graze. There was no difference ($P=0.42$) in ending weed frequencies between GS and GFS. Ending weed frequencies were higher ($P<0.01$) in GF treatment plots than GS or GFS treatment plots (Table 20).

3. Percent Change in Weed Frequencies. A site by treatment interaction was detected ($P<0.01$; Table 19; Appendix Table H) for percent change in weed frequencies. Therefore, results are presented as the simple effects of treatment within site.

a. GC versus GT. There was a difference ($P<0.01$) between GC and GT in percent change in weeds frequencies, weed frequencies increased in GC and decreased at in GT all four sites (Table 19; Appendix Table H).

b. GC versus Graze. A difference ($P<0.01$) was detected between GC and all grazing treatments, GC increased in percent change in weeds frequencies and GF, GS, and GFS decreased at all four sites (Table 19; Appendix Table H).

c. GT versus Graze. Percent change in weeds frequencies did not differ ($P>0.19$) at any of the four sites between GT and GF. At three out of the four sites, GT and GS did no differ ($P>0.11$) in percent change in weeds frequencies. At site 1, GS had a greater reduction ($P<0.01$) in percent change in weeds frequencies than GT (Table 19; Appendix Table H). At sites 1 and 2, percent change in weed frequencies were reduced more ($P<0.06$) in GFS than GT. Percent change in weeds frequencies in GT and GFS did not differ ($P>0.18$) at sites 3 and 4 (Table 19; Appendix Table H).

d. Graze. At three sites, there were no differences ($P>0.15$) in percent change in weeds between GF and GS. At site 1, GS had more of a reduction ($P<0.01$) in percent change in weeds than GF (Table 19; Appendix Table H). There was more of a reduction ($P<0.09$) in GFS at three sites than GF. At site 3, there were no differences ($P>0.25$) between GF and GFS for percent change in

weeds. Percent change in weeds did not differ ($P>0.14$) at three sites between GS and GFS. At site 1, GS had more of a reduction ($P<0.01$) in percent change in weeds than GFS (Table 19; Appendix Table H).

B. Fall Burned Versus Control, Fall Grazed, and Tilled Experiment

1. Beginning Weed Frequencies. No site by treatment interaction was detected ($P=0.90$) for beginning weed frequencies in burn treatment plots (Table 21). Therefore, the main effect of treatment across sites is presented.

2. Ending Weed Frequencies. No site by treatment interaction was detected ($P=0.28$) for ending weed frequencies (Table 21). Therefore, the main effect of treatment across sites is presented.

a. BC versus BB. Ending weed density was greater ($P<0.01$) in BC than BB (Table 21).

b BB versus BT. Burn had a lower ($P=0.03$) ending weed frequencies than BT (Table 21).

c. BB versus BF. Ending weed frequencies was greater ($P=0.02$) in BF than BB (Table 21)

3. Percent Change in Weed Frequencies. There was no site by treatment interaction detected ($P=0.67$; Table 21) for percent change in weeds. Therefore, the main effects of treatment across sites are presented.

a. BC versus BB. There was a difference ($P<0.01$) in the percent change of biomass between BC and BB, BC increased and BB decreased (Table 21).

b. BB versus BT. Burn had more of a reduction ($P<0.08$) in percent change in weeds than BT (Table 21).

c. BB versus BF. Percent change in weeds had more of a reduction in BB than BF ($P=0.01$; Table 21).

C. Trample Versus Control and Clip Experiment.

1. Beginning Weed Frequencies. Only one site (site 4) was analyzed due to drought (Table 22).

2. Ending Weed Frequencies.

a. TC versus TCP. Ending weed frequencies did not differ ($P=0.60$) between TC and TCP. (Table 22).

b. TC versus Trample. Ending weed frequencies did not differ ($P>0.20$) between TC and any trample treatments.

c. TCP versus Trample. No differences ($P>0.44$) were detected in ending weed frequencies between TCP and any of the trample treatments.

d. Trample. The trample treatments did not differ ($P>0.13$) in ending weed frequencies among each other.

3. Percent Change in Weed Frequencies.

a. TC versus TCP. Percent change in weeds did not differ ($P=0.84$) between TC and TCP (Table 22).

b. TC versus Trample. There were no differences detected ($P>0.32$) in percent change in weeds between TC and any of the trample treatments (Table 22).

c. TCP versus Trample. Percent change in weeds did not differ ($P>0.43$) between TCP and any of the trample treatments (Table 22).

d. Trample. No differences were detected ($P>0.25$) for percent change in weeds among trample treatments (Table 22).

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