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

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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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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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).

<u>Tillage.</u> 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 (Canillàs 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.

<u>Grazing</u>

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