



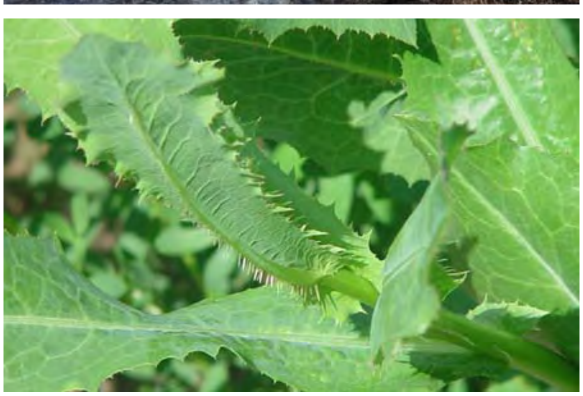

FINAL REPORT 2009-2011

Alternatives to Burning Crop Residues in Alfalfa Grown for Seed

Economic/Pest Management Impacts and Interactions between Selected Burning Alternatives and Precision Crop Spacing

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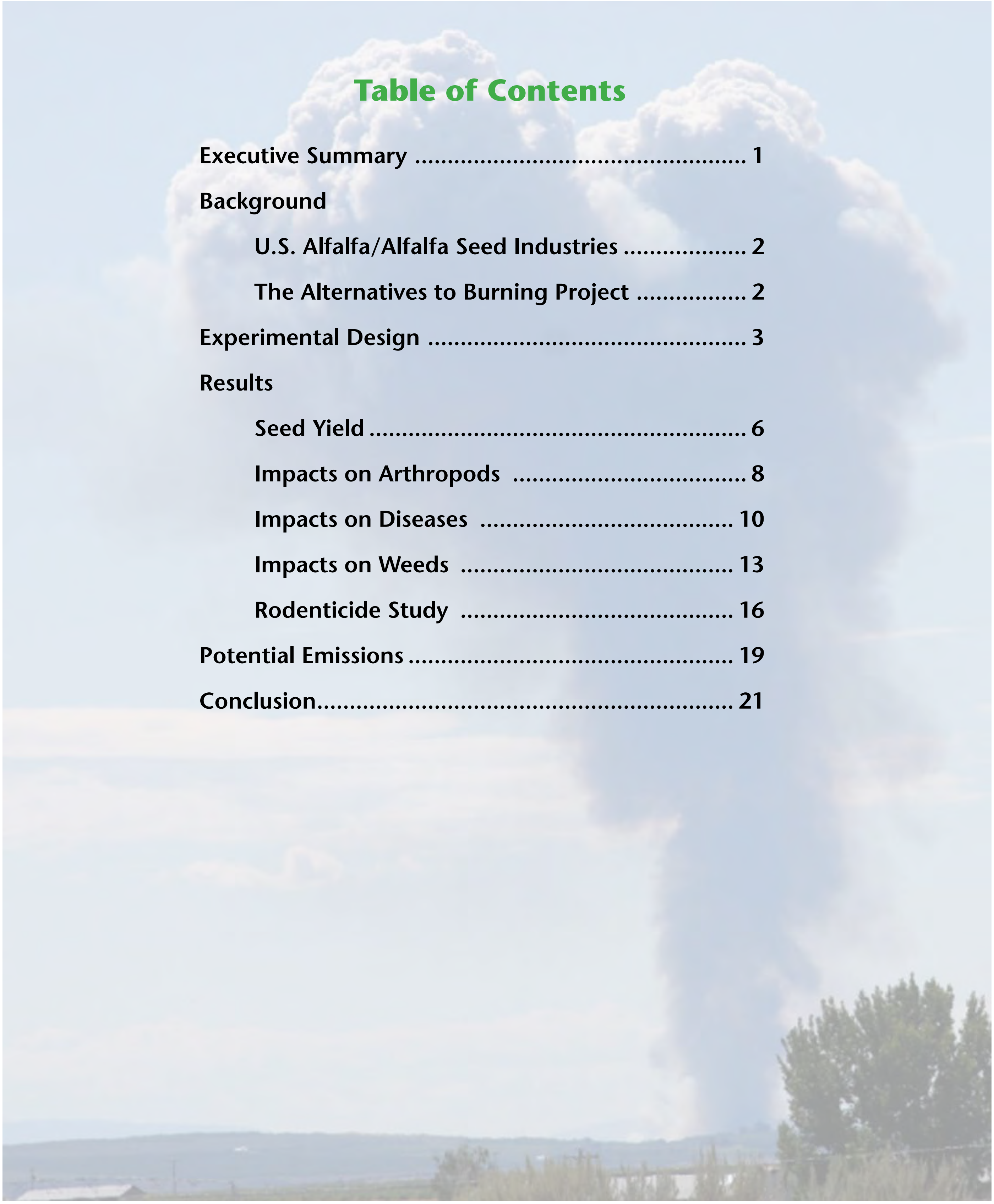

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Executive Summary

Project Rationale

Building on work conducted in two previous projects supported by the Agricultural Burning Practices and Research Task Force (2005–2007 and 2007–2009), we continued to evaluate the costs and benefits of selected alternatives to burning alfalfa seed crop residues in our 2009–2011 project. We examined four residue management treatments (burning, tillage, mowing/harvest, and untreated control) for their impacts on insect, weed, and disease pest abundance and severity and we calculated biomass yields and resultant smoke emissions. Interactions between each of the four treatments and planting at varying row spacings and varying seeding rates within the row were also studied.

Background

Alfalfa seed producers in Walla Walla County have traditionally burned alfalfa and weed residues in late winter. Burning has proven to be a cost-effective practice because it provides pest control of specific weeds, insects and diseases at minimal cost while simultaneously removing crop residues. In 2005–2007, we evaluated five experimental alternatives along with traditional stubble burning and an untreated control. The results from those studies suggested that further research into two practical alternatives to burning—residue tillage and harvest/removal of residue—was warranted. Of the various mechanical (non-chemical) methods of pest management, tillage is one of the most economical and shows potential for pest management efficacy. Removal (harvest) of crop residue has previously appeared to be cost-prohibitive, but emerging biofuels technologies present an opportunity for growers to realize income from harvested residues that could offset the baling and transport costs. We are zeroing in on a plant density that will optimize yields and minimize stubble residue and subsequent smoke emissions when burned.

Objectives

In summary, our project objectives included:

1. evaluating the interactions between plant density, tillage, burning, and removal of stubble on major disease, weed, and insect pests on established alfalfa grown for seed;
2. determining optimal plant density to maximize seed yield and minimize field residues; and
3. disseminating research results via meetings, publications, and the Internet.

Plot Establishment

Sixty-four research plots were established in Touchet, Washington in July 2007, in randomized complete block design of 4 replications per treatment. Pelleted alfalfa seed was planted at two row spacings (22 and 30 inches) and two seed spacings (1-5/8 and 3-3/8 inches) within the row. Alfalfa seed was grown under the grower's normal management practices in 2008.

Methods

Disease, weed, and insect pests were monitored and quantified beginning in the spring of the establishment year, 2008. Following the crop establishment year, four different alfalfa residue management practices (treatments) were imposed in the winters of 2009 and 2010: burning, mowing/harvest, tilling and doing nothing (untreated control, i.e., leaving the alfalfa residue on the surface). Each of these 4 treatments was applied on 4 replicate plots of each row spacing/seed density combination. In total we had 16 treatments replicated 4 times for a total of 64 plots. Disease, weed, and insect pests were monitored and quantified throughout each of the subsequent growing years (2009 & 2010) to determine whether the various plant densities and imposed treatments had impacts on pest populations, seed yields, and potential emissions. Additionally a rodent control study was conducted in winter 2010. The plots were harvested in July 2008, 2009, and 2010.

Results and Conclusions

In 2008, the plot establishment year, yields were optimum and residues were decreased in the 30-inch row with the 1-5/8-inch seed spacing treatment compared to standard grower practices. In 2009, the winter burning treatment significantly increased ($p<0.01$) seed yields consistently across all the row and seed density treatments. Stubble residue and smoke emission were minimized in the 22-inch row with 3-3/8-inch seed spacing. Similar results were obtained in 2010. Among all the treatments, burning provided the best suppression of disease, weeds, and rodents in this study.

Background

U.S. Alfalfa and Alfalfa Seed Industries

Forage alfalfa is a major input of the multi-billion-dollar U.S. livestock and dairy industries. Washington State alfalfa seed producers have earned a worldwide reputation for producing high-quality seed. International competition (primarily from Canada) as well as competition from other western states has decreased Washington State's market share in recent years. Washington State alfalfa seed producers' competitiveness has been further reduced by state and federal regulation. However, the development of a corn-based biofuels industry has increased the market price for field corn. Alfalfa provides a cost-effective alternative protein source for livestock producers and this presents an opportunity to Pacific Northwest forage producers. Alfalfa is a nitrogen-fixing plant that requires fewer fertilizer inputs than corn and oil seeds and alfalfa can be grown on marginal soil types on which corn cannot be produced. These factors should continue to increase the demand for high-quality Washington State alfalfa seed.

Alfalfa seed producers in specific unincorporated regions of Walla Walla County, Washington State are permitted to burn their fields under detailed regulations in order to remove crop residues at the end of a production cycle. (Note that alfalfa seed growers in the Columbia Basin are not permitted to burn, but they have a greater ability to rotate crops.) Experience had concluded that this practice decreased subsequent pressure from pest insects (alfalfa seed chalcids, weevils, Lygus), weeds (catchweed bedstraw, mayweed, prickly lettuce), and diseases (white mold, Verticillium wilt). Producers of alfalfa seed in this growing region had concluded that burning was and is an effective and economical means to several ends.

The Alternatives to Burning Project

In November 2004, the State of Washington Department of Ecology Air Quality Program released a publication entitled *Alternatives to Agricultural Burning: Agricultural Practices to Help Reduce or Eliminate the Need to Burn*. In the guidelines set forth in this document it is stated that "burning for pest control must have a long-term follow-up plan." This new mandate initiated the importance of studying alternatives to field burning in alfalfa seed.

The project for which we are submitting this final report has built on a course of research initiated by Washington State University (WSU) and USDA Agricultural Research Service (USDA-ARS) in 2005 and continuing through 2011 to increase alfalfa seed producers' competitiveness and help them comply with potential regulatory actions that may be taken in the future.

Lygus bug, prickly lettuce, white mold on alfalfa. Burning alfalfa seed crop residues was thought to reduce pressure from these pests.

In practice, the main alternative to field burning is incorporation (tillage) or removal (harvest) of hay or stubble combined. In this project we attempted to quantify how these alternative treatments compared to burning in terms of seed production and pest pressures. Pesticides provide obvious economic benefits but overuse can result in negative environmental impacts. Pesticide costs and application expenses are rising rapidly due to increases in fuel and labor costs. Pesticide resistance development, which can result from consistent use/overuse of specific pesticides or pesticide classes, is also a concern. Resistance (i.e., the adaptation of pest species to a pesticide resulting in decreased susceptibility) can occur in insect, weed, or disease pests. Alfalfa seed producers have observed and WSU researchers have documented the development of resistance to insecticides by Lygus bugs. Important alfalfa seed weed species including prickly lettuce and Western salsify have also exhibited the development of tolerance to several classes of commonly used herbicides. On the plus side, alfalfa grown for seed is considered a "non-food/non-feed" crop, a status that provides alfalfa seed producers the competitive benefit of being able to use pesticide chemistries that have either been eliminated through regulation on food/feed products or to obtain the use of new crop protection chemistries without having to go through the arduous process of establishing a food tolerance.

Harvest and removal of alfalfa seed residues has been impractical for growers because the process is expensive due to high labor inputs, high fuel costs, and expensive equipment; additionally, there has been no ready market for the straw. Stubble from alfalfa seed fields is low in protein and has poor digestibility, making it a low-quality livestock feed, and since alfalfa seed in Washington State is produced as a non-food/non-feed crop, the straw cannot be consumed by livestock. However, reducing the amount of residue through manipulating plant density is another way to reduce field stubble residue regardless of method of disposal, be it burning, tillage, or mowing. Our research explored plant density manipulation to gain further understanding of the impacts of various planting schemes.

Stubble from alfalfa seed fields has limited marketability.

Mowing is one way to deal with field residue (stubble.)

An unforeseen result of our study was a dramatic increase of rodent abundance (pocket gophers and voles) in the untreated check plots when the residue was left undisturbed. The field residue apparently provided food for rodents and created shelter from predatory birds.

Plant density (created by both the spacing of plant rows and in-row spacing of the plants) has been documented as having an impact on pest presence and subsequent management strategies. This is particularly true with respect to weeds during stand establishment. In our study, closely spaced plantings retained more moisture and provide greater shade, favoring development of certain diseases, while the wider row spacing and lower plant populations required additional weed management because the crop provided less weed suppression early in the growing season. Alfalfa seed growers have been experimenting with varying seeding rates and row spacing in recent years. Interest in greater competitiveness and high yields, coupled with the increasing availability of precision planting technologies, made the manipulation of planting densities an attractive agronomic and pest management tool within our experimental design. We therefore incorporated plant spacing as a critical variable in the final two years of our research, investigating its impacts on disease, weed, and insect pests, and quantity of field residue in interaction with the alternatives to burning we examined.

In the pages that follow, we report on various aspects of our studies, including resulting seed yields, impacts on arthropods, impacts on diseases, impacts on weeds, the incidental rodenticide study, and the potential emissions that could result from burning the plots with the various planting densities.

Experimental Design

Precision planter enables precise row spacing and spacing of seeds within the row.

On July 31, 2007, experimental plots were established within a commercial field in Touchet, Washington. Utilizing a precision Monosem vacuum planter provided by project partner Forage Genetics International, we planted pelleted alfalfa seed at two row spacings (22 and 30 inches) and two seed spacings (1-5/8 and 3-3/8 inches) in plots approximately 30 by 500 ft. Plots were established with all 4 possible combinations of the 2 row spacings and the 2 seeding rates. A total of 16 replicate plots of 30 to 33 feet wide by 490 or 720 feet were planted in each row spacing/ seeding density combination. The lowest seeding rate (30-inch row with 3-3/8-inch seeding rate) utilized 1/3 lb. of seed per acre, while the 22-inch rows with the 3-3/8-inch seeding rate utilized 4/10 lb. of seed per acre. The higher in-row spacing of one seed per 1-5/8 inches increased the lb./A rate by 100% to 150% for each of the row spacings.

The alfalfa seed in these plots was grown under the commercial grower's normal management practices in 2008, including the employment of a standard herbicide program at establishment. Weed density, white mold incidence, and insect populations were assessed at intervals during the establishment year, beginning in spring of 2008.

Seed spacing/row spacing schematic (not to scale).

In the winter following the 2008 crop establishment year, we superimposed four alfalfa hay residue (stubble) removal treatments on each of the row spacing/seed spacing combinations. The four treatments, applied in February 2009 and repeated in February 2010, were control (stubble not removed), tillage (stubble incorporated into the soil), burning (stubble burned), and stubble removal (majority of stubble harvested, baled, and removed from the field). The treatment subplots were arranged in a randomized complete block design, with each possible combination replicated 4 times. With the 4 seed/row spacing combinations x the 4 stubble removal treatments x 4 replications, we managed a total of 64 subplots.

Above: Plant spacing of 3-3/8 (top) and 1-5/8 inches. Below: Row spacing of 30 (top) and 22 inches.

Burning was conducted on the appropriate subplots on legal burn days. Fires were lit with propane torches and the fires were contained by WSU and USDA staff positioned along the perimeters of each respective plot.

Mowing was conducted with a Craftsman 26 HP 56-inch garden tractor mower with a bagger. Collected residues were loaded onto a trailer, and hauled off to an appropriate organic matter disposal site.

Tilling was accomplished with an agricultural tiller attached to our WSU 26 HP research tractor. The tiller was set to displace the top 3 inches of the soil surface.

Crop residue yields were collected from 45 sq. ft. of the burn plots in 2009 and from all of the plots in 2010 prior to residue treatment application.

In July 2009 and 2010 all of the plots were harvested with a combine harvester with an instantaneous yield meter. Yields were read 3 times per plot and an average score was calculated per plot.

All of the data sets mentioned above were analyzed by analysis of variance and the arithmetic sampled means from the various treatments were compared to the means from the untreated control plots in pairwise *t*-tests to determine if the treatments provided a significant difference compared to the non-treated control.

Winter of 2009:
Burning, tilling, and mowing treatments.

Seed Yield

Seed yields were taken in July 2009 following the establishment year and one year of winter treatment and in July 2010 following an additional production year and a second year of applied winter treatments. All of the plots were harvested with a combine harvester with an instantaneous yield meter. Yields were read 3 times per plot and an average score was calculated per plot. The resulting data were analyzed by analysis of variance and these results are detailed in Table 1, below. Seed yields in pounds per acre are given in Table 2, opposite page.

Since only the February treatment (burn, mow, till, and untreated check) was a significant ($p<0.05$) factor in determining seed yields (Table 1) the yields from both row spacings and seed spacings within the row were pooled for a direct analysis on treatment. The analysis of variance results are detailed in Table 3, opposite page. Figures 1 and 2 graphically display that residue burning resulted in significantly ($p<0.01$) greater seed yields than the other alternative treatments.

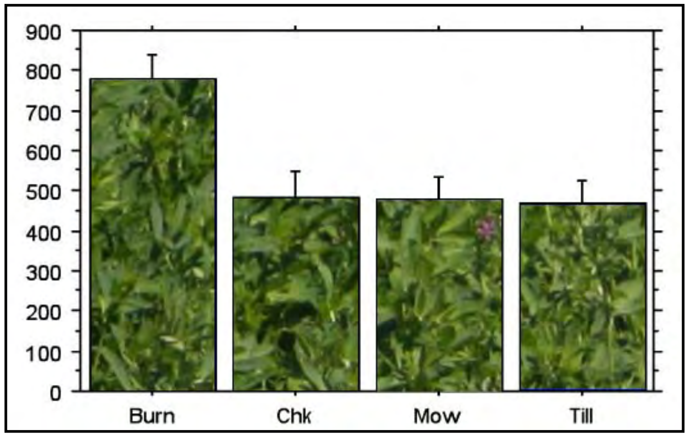


Figure 1. Yield in pounds per acre (±standard error of the mean) in 2009.

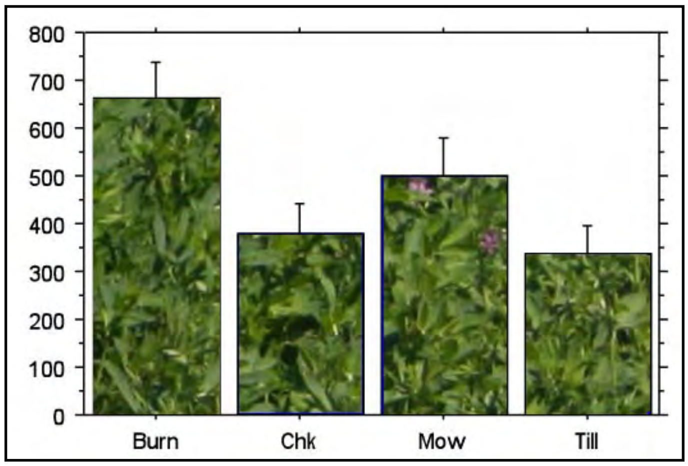
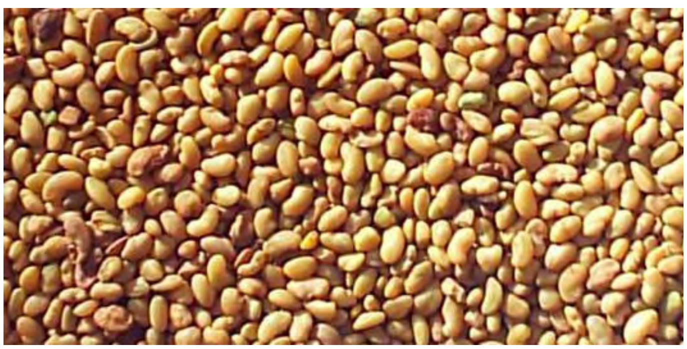


Figure 2. Yield in pounds per acre (±standard error of the mean) in 2010.



Alfalfa seed.

TABLE 1						
	2009			2010		
Source	*df*	Mean Square	*p*-value	*df*	Mean Square	*p*-value
Treatment	3	364,099	0.01	3	188,261	0.04
Row Spacing	1	104,571	0.17	1	31,780	0.47
Seed Spacing	1	12,404	0.63	1	118,747	0.17
T x Rs	3	122,021	0.09	3	33,871	0.65
T x Ss	3	97,610	0.15	3	43,703	0.55
Rs x Ss	1	42,900	0.37	1	68,322	0.30
T x Rs x Ss	3	33,571	0.60	3	1,831	0.99
Error	48	53,469		31	61,486	

Table 1. ANOVA effects for treatment (burn, mow, till, check), row spacing (22-inch, 30-inch), and seed spacing in row (1-5/8 inches, 3-3/8 inches), and their interactions on seed yield in 2009 and 2010.

TABLE 2

			2009		2010	
Treatment	Row Spacing	Seed Spacing	Pounds per acre ± SE		Pounds per acre ± SE	
Burn	22″	1-5/8″	885±136	n=4	792±328	n=2
Burn	22″	3-3/8″	845±130	n=4	533±165	n=2
Burn	30″	1-5/8″	682±130	n=4	687±126	n=2
Burn	30″	3-3/8″	697±107	n=4	632± 93	n=2
Check	22″	1-5/8″	716±201	n=4	582±124	n=4
Check	22″	3-3/8″	449± 91	n=4	361±123	n=4
Check	30″	1-5/8″	387± 32	n=4	376±174	n=3
Check	30″	3-3/8″	382± 71	n=4	246± 57	n=4
Mow	22″	1-5/8″	326± 70	n=4	567±240	n=3
Mow	22″	3-3/8″	448± 50	n=4	552± 64	n=3
Mow	30″	1-5/8″	387± 79	n=4	360±145	n=3
Mow	30″	3-3/8″	742±158	n=4	529±170	n=3
Till	22″	1-5/8″	488±131	n=4	433±114	n=3
Till	22″	3-3/8″	576± 89	n=4	203± 57	n=4
Till	30″	1-5/8″	428±123	n=4	424±189	n=3
Till	30″	3-3/8″	381±127	n=4	342±116	n=3

Table 2. Seed yields in pounds (± standard error of the mean) per acre as read off the instantaneous yield meter on the combine harvester July 2009 and July 2010.

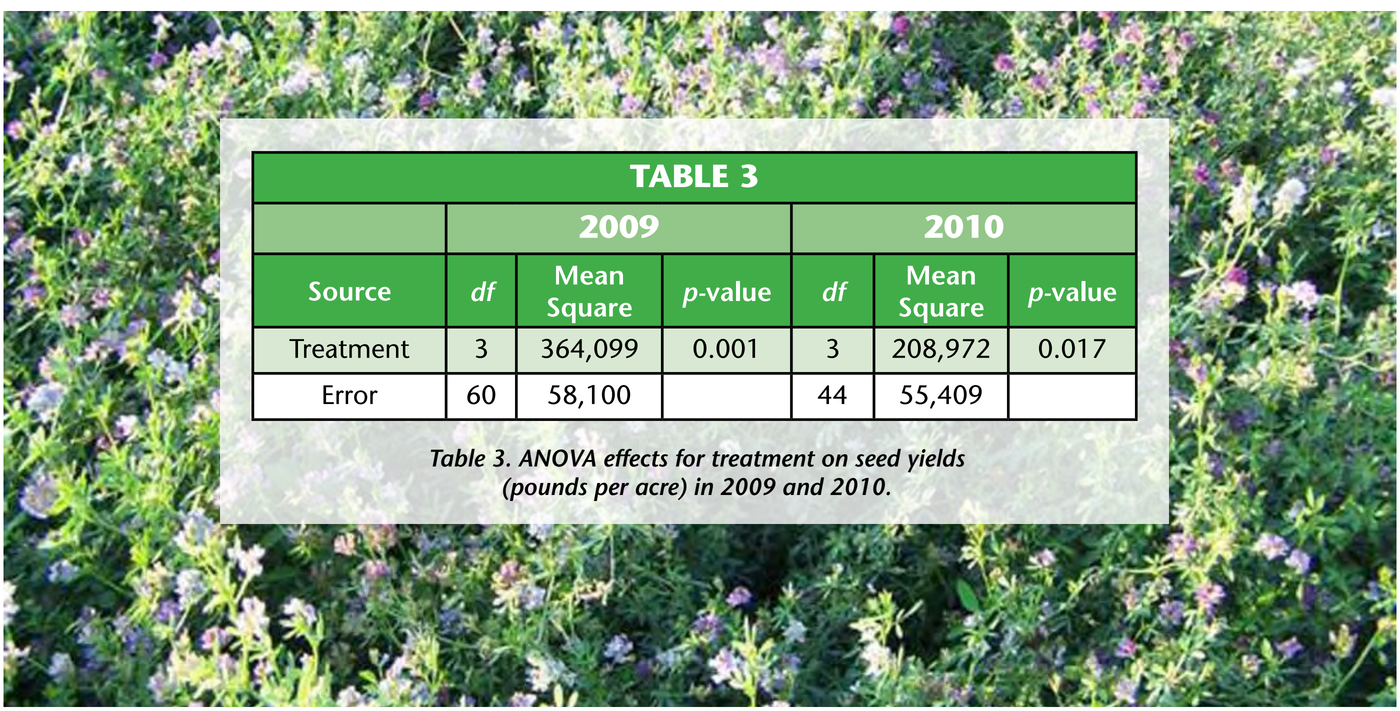


TABLE 3

	2009			2010		
Source	*df*	Mean Square	*p*-value	*df*	Mean Square	*p*-value
Treatment	3	364,099	0.001	3	208,972	0.017
Error	60	58,100		44	55,409	

Table 3. ANOVA effects for treatment on seed yields (pounds per acre) in 2009 and 2010.

Impacts on Arthropods

Alfalfa seed growers in the Touchet region of Washington State believe that alfalfa seed chalcids, Lygus bugs, and alfalfa weevil are less problematic following a burn. Burning of alfalfa seed residue is known to reduce alfalfa seed chalcid populations and our previous research for the Agricultural Burning Practices and Research Task Force in 2005-2007 confirmed that burning had suppressive impacts on Lygus populations, as did tilling and insecticide applications.

Lygus bugs (shown at left, on clover) are the most important pest of alfalfa seed, according to the USDA-CSREES *Pest Management Strategic Plan for Western U.S. Alfalfa and Clover Seed Production* (http://www.ipmcenters.org/pmsp/pdf/WestAlfalfaCloverSeed.pdf); it is therefore crucial that any viable alternative to burning also have impacts on Lygus. The insect component of our work focused on Lygus but we also examined the impacts of the various treatments on other pest and beneficial fauna of alfalfa seed.

Photo below: Technician with sweep net.
Photos opposite, from top: Deploying pitfall trap, yellow sticky card, emptying sweep net.

Materials and Methods

Insect populations were monitored by various methods as the alfalfa broke dormancy in April 2009 and 2010. Pitfall traps were utilized to monitor ground-dwelling arthropods, yellow sticky card traps were utilized to monitor flies, and sweep net samples were taken to monitor both flies and Lygus. Samples were taken from each possible combination of treatments with four replications in a randomized block design. Pitfall and yellow sticky card traps were assessed weekly during this period and five sweep net samples were taken on 9 April and 16 April. Beneficial and pest arthropods were quantified and the plots were subsequently treated with Lorsban (May 27, 2009) or Lorsban and Bifenture (May 30, 2010), followed by Beleaf (June 11, 2009 and June 10, 2010).

Results

Arthropod counts ± standard error are presented in Table 4. There were no significant differences in insect abundance among the various row spacings and seeding within the row densities with the exception of Lygus abundance in the burn and till treatments. However, the absolute numbers of Lygus adults present were so low as to be biologically irrelevant in 2009 and 2010 (data not shown).

TABLE 4

Carabid Beetles Captured per Week in Pitfall Traps - 2009

Treatment	4/2/09	4/9/09	4/16/09	4/23/09
Burn	1.00±0.22	1.78±0.62	0.81±0.26	1.30±0.52
Control	1.12±0.30	2.07±0.50	1.14±0.42	2.50±0.78
Mow	1.53±0.35	1.81±0.38	1.19±0.40	1.93±0.52
Till	1.37±0.34	2.12±0.34	0.47±0.21	1.17±0.30

Carabid Beetles Captured per Week in Pitfall Traps - 2010

Treatment	4/6/10	4/13/10	4/20/10	4/27/10
Burn	0.25±	0.50±0.29	0.25±0.25	0
Control	0.75±0.25	0	0	0.25±0.25
Mow	00.48	0.25±0.25	0	0.25±0.25
Till	0	0	0	0.25±0.25

Spiders Captured per Week in Pitfall Traps - 2009

Treatment	4/2/09	4/9/09	4/16/09	4/23/09
Burn	0.44±0.16	0.44±0.16	0.71±0.22	1.50±0.34
Control	0.31±0.12	0.31±0.12	1.31±0.24	0.70±0.26
Mow	0.87±0.33	0.87±0.37	0.94±0.25	1.43±0.43
Till	0.87±0.24	0.87±0.24	1.31±0.36	1.00±0.27

Spiders Captured per Week in Pitfall Traps - 2010

Treatment	4/6/10	4/13/10	4/20/10	4/27/10
Burn	0	0.25±0.25	0.25±0.25	0.67±0.33
Control	0.75±0.48	0.25±0.25	0.25±0.25	0.25±0.25
Mow	0.25±0.25	0.25±0.25	0	0.25±0.25
Till	0.75±0.48	0.25±0.25	0.75±0.25	0.75±0.25

Flies Captured per Week on Yellow Sticky Card Traps - 2009

Treatment	4/2/09	4/9/09	4/16/09
Burn	2.31±0.44	15.81±1.35	28.18±2.85
Control	2.13±0.27	17.44±1.52	25.31±3.17
Mow	2.46±0.51	12.31±1.30	25.93±2.45
Till	2.67±0.50	14.62±1.46	29.87±2.26

Flies Captured per Week on Yellow Sticky Card Traps - 2010

Treatment	4/13/10	4/20/10	4/27/10
Burn	0.71±0.23	13.21±6.55	19.20±3.11
Control	1.01±0.17	12.45±4.21	17.13±4.31
Mow	0.79±0.09	19.33±7.81	13.39±2.35
Till	1.19±0.21	24.46±9.46	9.61±3.51

Lygus Adults Captured per Week per 5 Sweeps with Net - 2009

Treatment	4/9/09	4/16/09
Burn	0.06±0.06*	0.12±0.08*
Control	0.31±0.17	0.31±0.12
Mow	0.18±0.10	0.25±0.11
Till	0.60±0.06	0.06±0.06*

*Lygus populations significantly (p<0.05) lower than in control plots.

Table 4. Selected arthropod counts ± standard error.

Impacts on Diseases

Sclerotinia crown and stem rot caused by *Sclerotinia sclerotiorum,* also known as white mold, can be a major disease in alfalfa seed production, therefore this pathogen was the focus of the disease component of our project. When Sclerotinia rots are present, they can result in major yield losses for Washington alfalfa seed growers. The pathogen is particularly problematic in the spring and late fall when weather conditions are cool and moist, as was the case in 2010. Inoculum levels in seed fields in Washington have been found to exceed 1400 sclerotia per square meter.

Currently there are no alfalfa cultivars with resistance to white mold. Foliar fungicides effective against white mold are expensive and are not permitted for use on alfalfa. Alternative disease management strategies are needed to limit the impact of this disease.

White mold, a major disease in alfalfa seed production.

Materials and Methods

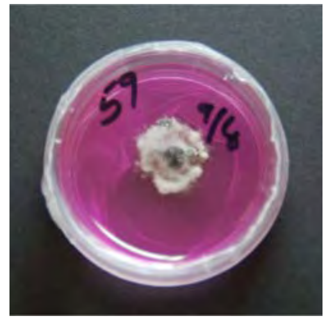
The top half inch of soil, in addition to the plant surface debris, was collected from one square meter of soil from the center of each alfalfa treatment plot on March 4, 2009 and March 16, 2010, using the flat edge of a hand-held trowel blade marked at the half-inch (1.27 cm) level. Four replicated plots were established for each of the sixteen treatments (Table 5). Soil from each plot was placed in sealable 1 gallon plastic bags and transported to a greenhouse where it was allowed to air dry for two to three weeks at temperatures ranging from 65 to 75°F. After drying, the soil was placed in a cool room at 60°F until processed. Sclerotia were isolated from the soil by a sequence of sievings, then were transferred to plastic bags. To verify their identity, each sclerotium was lightly nicked at the surface with a razor blade to expose the white pith inside. Sclerotia recovered from soil within each of the four replicated plots of each treatment were counted and the mean number for each treatment was determined.

One of 64 square-meter plots, from which the top half inch of soil and plant debris were collected.

TABLE 5		
Array of Treatments (each replicated x4)		
Row Spacing	Seed Spacing	Treatment
30″	1-5/8″	Non-treated
30″	1-5/8″	Burn
30″	1-5/8″	Mow
30″	1-5/8″	Till
30″	3-3/8″	Non-treated
30″	3-3/8″	Burn
30″	3-3/8″	Mow
30″	3-3/8″	Till
22″	1-5/8″	Non-treated
22″	1-5/8″	Burn
22″	1-5/8″	Mow
22″	1-5/8″	Till
22″	3-3/8″	Non-treated
22″	3-3/8″	Burn
22″	3-3/8″	Mow
22″	3-3/8″	Till

Table 5. List of sixteen treatments assessed to determine the impact of row spacing, seed spacing and stubble management practices on deposition and survival of Sclerotinia sclerotiorum *sclerotia in an alfalfa seed production field soil.*





From left: Sclerotinia in-situ and shown with coin for scale; sifting sclerotina in the lab; testing individual sclerotia for viability (one of 1128 plated).

We next determined sclerotium viability by sterilizing and plating 30 randomly selected sclerotia from each plot onto a germination medium. (If fewer than 30 sclerotia were collected from a plot, then all of the sclerotia were plated.) Individual sclerotia were then placed in separate Petri dishes with the same germination medium, sealed, and placed in the dark at 77°F for a time sufficient for all viable sclerotia to germinate (23 days in 2009 and 18 days in 2010). Viability was determined by their ability to germinate and form new sclerotia. Fungi that colonized sclerotia and prevented germination and formation of new sclerotia were identified and grouped for analysis.

Results

In both 2009 and 2010, more sclerotia were found in the plots that were not burned. In 2009, the total number of sclerotia was 41% less in the soil of the burned plots than in the soils of the non-burned (i.e., untreated control, tilled, and mowed) plots, while in 2010, the total number was significantly less, 71%, $P = 0.015$. Plots that were burned also had less sclerotia survival, with survival rates of 9.4% and 10.7% less in 2009 and 2010, respectively. While the heat from the fire did not kill the sclerotia, according to our study (i.e., there was no discernable relationship between burning and percentage of sclerotia that failed to germinate), a reduction in the total number of sclerotia and in the survival rate of sclerotia—both of which did occur in the burned plots—may reduce the risk of a serious outbreak of Sclerotinia rot, especially when conditions might otherwise favor infection.

The average number of sclerotia found in a square meter of was 33.6. The greatest number found in a single square meter was 174 (at the 22-inch row spacing and 3-3/8-inch seed spacing), while the least number was 0 (at the 30-inch row spacing and 1-5/8-inch seed spacing). The average survival rate of sclerotia in the soil was 49.7%. The maximum survival rate of sclerotia collected from a single plot, when a minimum of 30 were plated, was 93.3% (from a mowed plot with 30-inch row spacing and 1-5/8-inch seed spacing) in 2009 and 73.3% (from a mowed plot with 22-inch row spacing and 1-5/8-inch seed spacing) in 2010. The minimum survival rate when at least 30 were plated was 13.3% (from a burned plot with 30-inch row spacing and 3-3/8-inch seed spacing) in 2009 and 13.3% (from a non-treated control plot with 22-inch row spacing and 3-3/8-inch seed spacing) in 2010. A total of 4,600 sclerotia were collected from the field plots in 2010. In the final analysis, row spacings and seed spacings did not appear to have an effect on number of sclerotia, viability of sclerotia, or type of fungi colonizing the sclerotia present. The post-harvest stubble treatments, however, did result in significant differences (Table 6).

TABLE 6

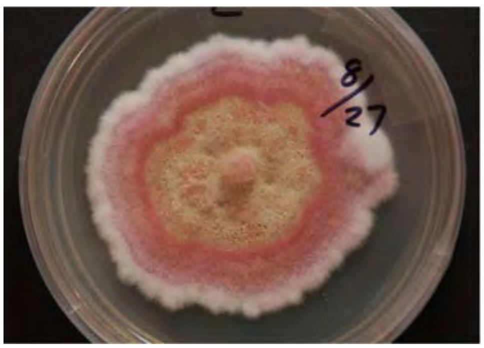
Impact of Treatments on Sclerotia Number and Viability

Stubble treatment	Mean number of sclerotia 2009[1]	Mean number of sclerotia 2010	% Viability of sclerotia 2009	% Viability of sclerotia 2010
Non-treated	41.9 a	115.2 a	51.1 a	38.6 b
Burn	24.9 a	33.9 b	41.7 a	27.9 c
Mow	41.3 a	103.8 a	49.8 a	50.2 a
Till	29.1 a	139.4 a	58.1 a	44.4 ab
P-value	0.555	0.015	0.316	0.021

[1] Numbers followed by same letters are not significantly different at the indicated *P*-value.

Table 6. Impact of stubble management treatments on the mean number and viability of sclerotia recovered from 1 meter square plots of soil in 2009 and 2010.

We found that the sclerotia were colonized primarily by fusaria (nine isolates) and *Ulocladium atrum*. *Fusarium acuminatum* appeared to be the most effective fungus in colonizing sclerotia and limiting spore viability, but unfortunately its potential as a biological control agent is very doubtful, as it is has been implicated in crown and root rotting on alfalfa and is also associated with diseases on some of the crops grown in rotation with alfalfa. More sclerotia were colonized by *F. acuminatum* in burned plots than in untreated (control) plots or plots that were mowed or tilled (Table 7).



Fusarium acuminatum ***appeared to be the most effective fungus in colonizing sclerotia.***

Ulocladium atrum ***was also effective in colonizing some of the sclerotia plated.***

In summary, our plant pathology research indicated that burning can significantly reduce the total number of sclerotia present in an alfalfa field, significantly reduce the percent viability of sclerotia, and significantly favor the colonization of sclerotia by *Fusarium acuminatum*. None of the other stubble management strategies showed increased benefits for controlling Sclerotinia rot above and beyond the burn treatment. This research indicates that if growers were to lose the ability to burn their fields, the number of viable sclerotia in the soil would likely increase, thereby increasing the risk of Sclerotinia rot infection in alfalfa seed production fields.

Partial collection of sclerotia colonizing fungi.

TABLE 7

Impact of Treatments on Colonization of Sclerotia by Various Fungi

Stubble treatment	*Fusarium acuminatum* 2009[1,2]	*Fusarium acuminatum* 2010	*Ullocladium atrum* 2009	*Ullocladium atrum* 2010	Other fungi 2009	Other fungi 2010
Non-treated	17.9 b	19.2 ab	17.0	6.0	13.9	22.2 b
Burn	23.8 a	24.2 a	7.8	4.0	25.7	38.9 a
Mow	14.4 b	12.7 bc	21.2	5.3	14.5	24.4 b
Till	10.5 b	9.2 c	20.8	5.5	10.6	24.9 b
P-value	0.0586	0.0533	0.231	0.888	0.0938	0.0540

[1] All numbers given as percentages. [2] Numbers followed by the same letters are not significantly different at the indicated *P*-value. If no letters are present, there are no significant differences at the indicated *P*-value.

Table 7. Mean percent of sclerotia colonized by **Fusarium acuminatum**, **Ullocladium atrum** *and other fungi following the various stubble treatments imposed in 2009 and 2010.*

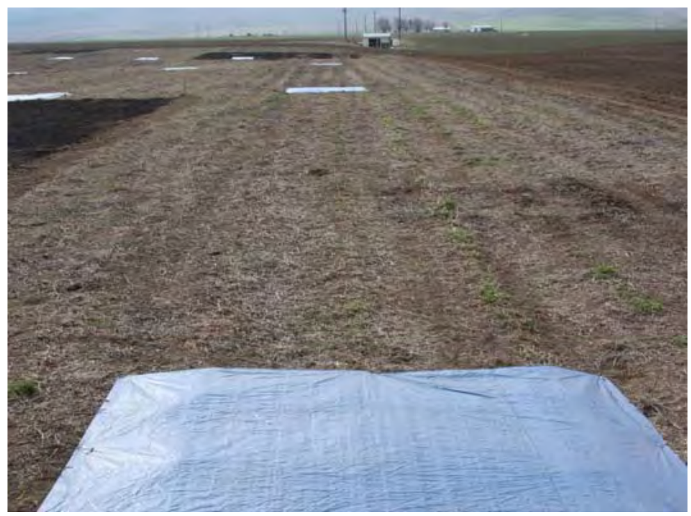
Impacts on Weeds

Winter annual weeds have historically been difficult to control in alfalfa seed production. Species that have the ability to germinate in the fall or spring, such as prickly lettuce and catchweed bedstraw, are particularly troublesome. Prickly lettuce has also developed resistance to imazethapyr and imazamox, two herbicides commonly used in alfalfa seed production. For the weed science component of the project, we studied the impacts of the various stubble removal treatments and the density spacings on the weed complex and the efficacy of various herbicides. We also tested the germinability of weed seed after burning as compared to nonburned control plots.

The presence or absence of crop residues, including burned residues, can impact weed seedling establishment and survivability by shading, affecting moisture retention near the soil surface, affecting fungal and bacterial seed pathogens, and possibly releasing allelopathic compounds. Herbicides that control weeds well in burned fields may have greater or lesser impacts in nonburned fields. For example, crop residues can bind herbicides or prevent them from reaching the soil surface. Removing crop residues may therefore improve performance of herbicides with soil residual activity, such as simazine, hexazinone, diuron, metribuzin, trifluralin, and pendimethalin.

From top left, clockwise: Western salsify, prickly lettuce, mayweed chamomile, catchweed bedstraw.

Tarped burned (above) and mowed (below) plots.



Materials and Methods: Weed Incidence and Herbicide Interaction

In the month following the various stubble treatments imposed in the winters of 2009 and 2010, we covered an approximately 8-foot by 10-foot section within each of the plots prior to the grower's application of herbicides. The burn, till, and mow treatments were conducted in February. We tarped the plots on March 6, 2009 and on March 4, 2010. The grower applied pendimethalin, simazine, and paraquat on March 9, 2009 and March 4, 2010. Our purpose in tarping the plots was to create an untreated control area within each plot. We then isolated areas of one square meter within the treated and nontreated (tarp-covered) areas and counted the weeds, sorting them by species, on May 19, 2009 and May 12, 2010.

Results:
Weed Incidence and Herbicide Interaction

Western salsify and prickly lettuce were the two most prevalent weeds in the trial in both 2009 and 2010. In 2009, the only significant effect on prickly lettuce population density was the herbicide treatment. In tarped areas that didn't receive any herbicide, prickly lettuce density ranged from 204 to 329 plants per square meter (plants/m^2) in 2009 and was not significantly affected by row spacing, seed spacing, or the four residue management treatments, but tended to be greatest in the tilled treatments (Figure 3, left side). In 2010, herbicide application had the greatest impact on prickly lettuce population density (Pr>0.0001) and there was a significant effect of residue management (Pr>0.038) and a significant residue management by herbicide interaction (Pr>0.04). In 2010, prickly lettuce ranged from 38.5 to 124 plants/m^2 in the tarped areas (no herbicide) and was greatest in the tilled plots and least in the burned plots (Figure 3, left side). Simazine controlled prickly lettuce well over all residue management treatments in both years, reducing plant population to fewer than 0.4 plants/m^2.

Western salsify population density was not affected by row spacing or seed spacing in either year, but was significantly affected by residue management and herbicide treatment and there was a significant residue management by herbicide interaction (Pr > 0.0049) only in 2009. In mowed and no residue removal treatments (no tillage or burning) with herbicide, salsify density ranged from 64 to 112 plants/m^2. Western salsify density was lowest in the burn and till treatments and was further reduced by herbicide treatment, although control was never complete (Figure 3, right side). Burning followed by simazine treatment reduced salsify density to 3.8 plants/m^2 in 2009. Salsify population density was greater in 2010 and averaged about 200 plants/m^2 in the mowed and the no residue management plots when no herbicide was applied. In 2010, field burning reduced salsify population density to 8.8 plants/m^2 in the no herbicide plots and 0.8 plants/m^2 when herbicide was applied (Figure 3, right side). As in 2009, tillage also reduced salsify population density compared to mowing or no residue management.

Western salsify, a biennial weed, is most prevalent in perennial crops where tillage is infrequent or absent. These results demonstrate the impact of soil disturbance and field burning on the incidence of Western salsify. Western salsify can germinate in late summer, autumn, late winter, and early spring. In this study, shallow cultivation in early spring greatly reduced the incidence of salsify. Burning also destroyed many seeds on the soil surface and possibly some small seedlings. Later spring germinating seedlings were controlled to a great extent by the preemergence herbicide treatment in early March. Dr. Lyndon Porter has also identified that Western salsify is a host for white mold *(Sclerotinia trifoliolum)* and that some salsify seedling mortality resulted from white mold infection in 2010 in this trial.

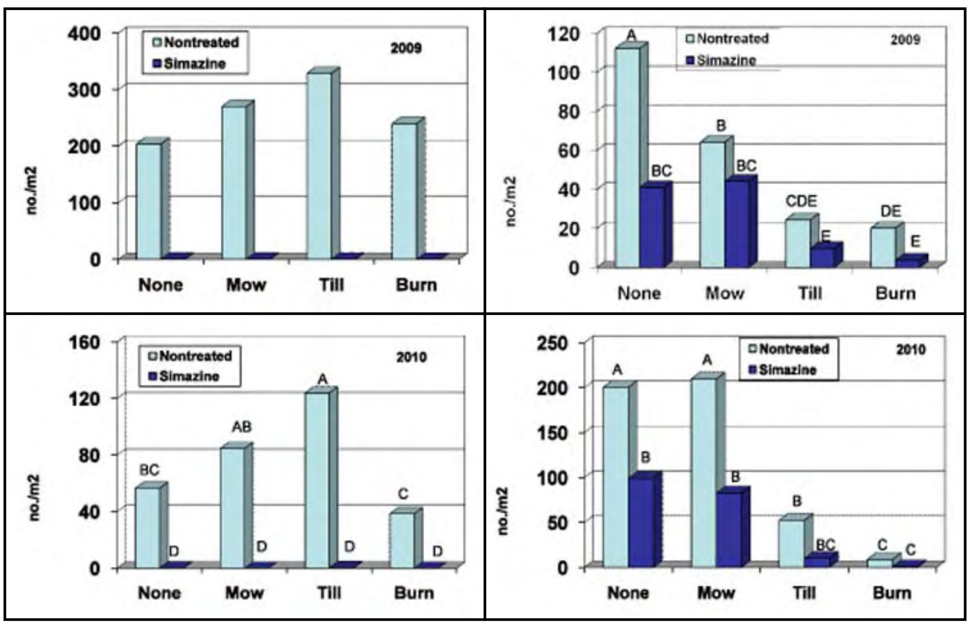


Figure 3. Prickly lettuce (left) and Western salsify (right) population densities in alfalfa seed May 19, 2009 and May 12, 2010 following various residue management treatments.

Prickly lettuce seedlings emerge from a field after a burn treatment.

Western salsify emergence is visibly less in the burned (left) than mowed (right) plot.

Materials and Methods: Weed Seed Germinability

For the weed seed germinability study, we collected weed seeds in the late summer of 2008 and 2009 from mayweed chamomile (also known as dog fennel, *Anthemis cotula)*, prickly lettuce *(Lactuca serriola)*, and Western salsify *(Tragopogon dubious)* in an alfalfa seed field near Touchet, Washington. We stored the seed in our laboratory in Prosser at 68°F. Into each of a series of stainless steel mesh packets measuring approximately 3 x 3 inches, we placed 100 weed seeds. On January 20, 2009 and February 22, 2010, we placed the packets of seeds either on the soil surface or buried an inch deep in the alfalfa seed field near Touchet. Surface packets were covered lightly with a small amount of alfalfa residue. Plots were burned on February 18, 2009 and March 2, 2010. Seed packets were subsequently recovered, seed removed, and germination tested in Petri dishes at 59°F in the dark on March 5, 2009 and March 4, 2010. Germinated seedlings were counted and removed every 2 to 4 days for three weeks.

Results: Weed Seed Germinability

Germination of mayweed chamomile from seed that had been stored in the lab at 68°F was 25% in 2009 and 16.5% in 2010, respectively, which indicates some induced dormancy had occurred (Table 8). Mayweed seed that was buried one inch below the soil surface in the field germinated 69% in 2009 and 26 to 31% in 2010, regardless of field burning. Mayweed seed placed on the soil surface germinated 49% in 2009 and 21% in 2010. Field burning totally eliminated germination of seed placed on the soil surface both years (Table 8).

Prickly lettuce and salsify germinated 90% or more in all treatments both years except where seed was placed on the soil surface and subjected to burning (Table 8). Field burning greatly reduced prickly lettuce seed germination to 1.3% and 1.8% in 2009 and 2010, respectively. Field burning reduced salsify germination to 5% and 22.8% in 2009 and 2010, respectively (Table 8).

Burning nearly destroyed all seed from these three species when seed packets were placed on the soil surface, but had no effect on seed buried 2.5 cm deep. The three species tested all normally are disseminated by wind and would typically be distributed near the soil surface in late summer and autumn. Burning of alfalfa residues is therefore an effective means to destroy many weed seeds that remain on the soil surface.

In the course of conducting the weed research component of our project, we also augmented the registration of new herbicide options for alfalfa seed production.

Above: Burying seed packets.
At right: Surface seed packets after a burn treatment.

TABLE 8						
	2009			2010		
Seed Placement/ Burn Treatment	Mayweed [1,2]	Prickly Lettuce	Salsify	Mayweed	Prickly Lettuce	Salsify
Lab Control	25.0	98.8	99.3	16.5	98.8	99.5
Surface Placement						
No burn	49.0 a	90.0 a	97.3 a	21.3 a	99.0 a	99.0 a
Burned	0 b	1.3 b	5.0 b	0 b	1.8 b	22.8 b
Buried (2.5 cm)						
No burn	68.8 a	94.3 a	96.3 a	30.8 a	94.0 a	99.5 a
Burned	68.5 a	95.0 a	99.5 a	25.5 a	99.5 a	92.3 a

[1] Numbers indicate percentage of germination. [2] Means within a column followed by the same letter are not significantly different per Fisher's protected least significant different test at $P = 0.05$.

Table 8. Effects of February field burning on the germination of three weed species from seed packets placed on the soil surface or buried 2.5 cm in an alfalfa seed field near Touchet, WA.

Rodenticide Study

Background

At left: Gopher, courtesy National Park Service. Above: Gopher mounds, courtesy USDA Forest Service, Bugwood.org.

Gophers are burrowing rodents. Also known as pocket gophers, this name comes from the fur-lined, external cheek pouches, or pockets, they use for carrying food and nesting materials. Gophers are well equipped for a digging, tunneling lifestyle with powerfully built forequarters; large-clawed front paws; fine, short fur that doesn't cake in wet soils; small eyes and ears; and highly sensitive facial whiskers that assist with moving about in the dark. Gophers' lips also are unusually adapted for their lifestyle; they can close them behind their four large incisor teeth to keep dirt out of their mouths when using their teeth for digging.

Mounds of fresh soil are the best sign of a gopher's presence. Gophers form mounds as they dig tunnels and push the loose dirt to the surface. Typically mounds are crescent or horseshoe-shaped when viewed from above. The entrance hole, which is off to one side of the mound, usually is plugged with earth by the gopher. One gopher can create several mounds in a day. Pocket gophers live in a burrow system that can cover an area of 200 to 2,000 square feet. The burrows are about 2-1/2 to 3-1/2 inches in diameter. Feeding burrows usually are 6 to 12 inches below ground, and the nest and food storage chamber can be as deep as 6 feet. Short, sloping lateral tunnels connect the main burrow system to the surface; gophers create these while pushing dirt to the surface to construct the main tunnel.

Gophers don't hibernate and are active year-round, although fresh mounding may not be present. They also can be active at all hours of the day. Gophers usually live alone within their burrow system, except when females are caring for their young or during breeding season. Gopher densities can be as high as 60 or more per acre in irrigated alfalfa fields. Gophers reach sexual maturity about 1 year of age and can live up to 3 years. In irrigated sites, gophers can produce up to 3 litters per year. Litters usually average 5 to 6 young.

Gophers are herbivorous and feed on a wide variety of vegetation but generally prefer herbaceous plants like alfalfa. In addition to direct damage to the crop created by their feeding, gophers' mounds and tunnels can interfere with field operations.

Voles are mouse-like rodents somewhat similar in appearance to pocket gophers. They have a compact, heavy body, short legs, short-furred tail, small eyes, and partially hidden ears. Their long, coarse fur is blackish brown to grayish brown. When fully grown they can measure 5 to 8 inches long, including the tail. Voles are active day and night, year-round. They are normally found in areas with dense vegetation. Voles dig many short, shallow burrows and make underground nests of grass, stems, and leaves. In areas with winter snow, voles will burrow in and through the snow to the surface.

Vole populations fluctuate from year to year; under favorable conditions their populations can increase rapidly. In some areas their numbers are cyclical, reaching peak numbers every 3 to 6 years

Vole, courtesy USDA-APHIS Wildlife Service.

before dropping back to low levels. Voles may breed any time of year, but the peak breeding period is spring. Voles are extremely prolific, with females maturing in 35 to 40 days and producing five to ten litters per year. Litter size ranges from three to six. However, voles seldom live past 12 months of age.

Voles cause damage to alfalfa when they gnaw on its roots, disrupting the flow of nutrients and water to the alfalfa plant. Voles also feed above ground on plant crowns as the alfalfa plant breaks dormancy.

Rodent Control

In alfalfa produced for seed, baiting with toxic baits is the most common control strategy. Strychnine-treated grain is the most common type of bait used for pocket gopher control. This bait generally contains 0.5% strychnine and is lethal with a single feeding. Baits containing 2.0% zinc phosphide are also available. As with strychnine, these baits are lethal after a single feeding.

A multiple-feeding anti-coagulant, chlorophacinone, has recently been registered on alfalfa. Anticoagulant baits in general are less toxic and will require multiple feedings to render a toxic dose. As such, they are preferred in areas where children, pets, or non-target wildlife might be present.

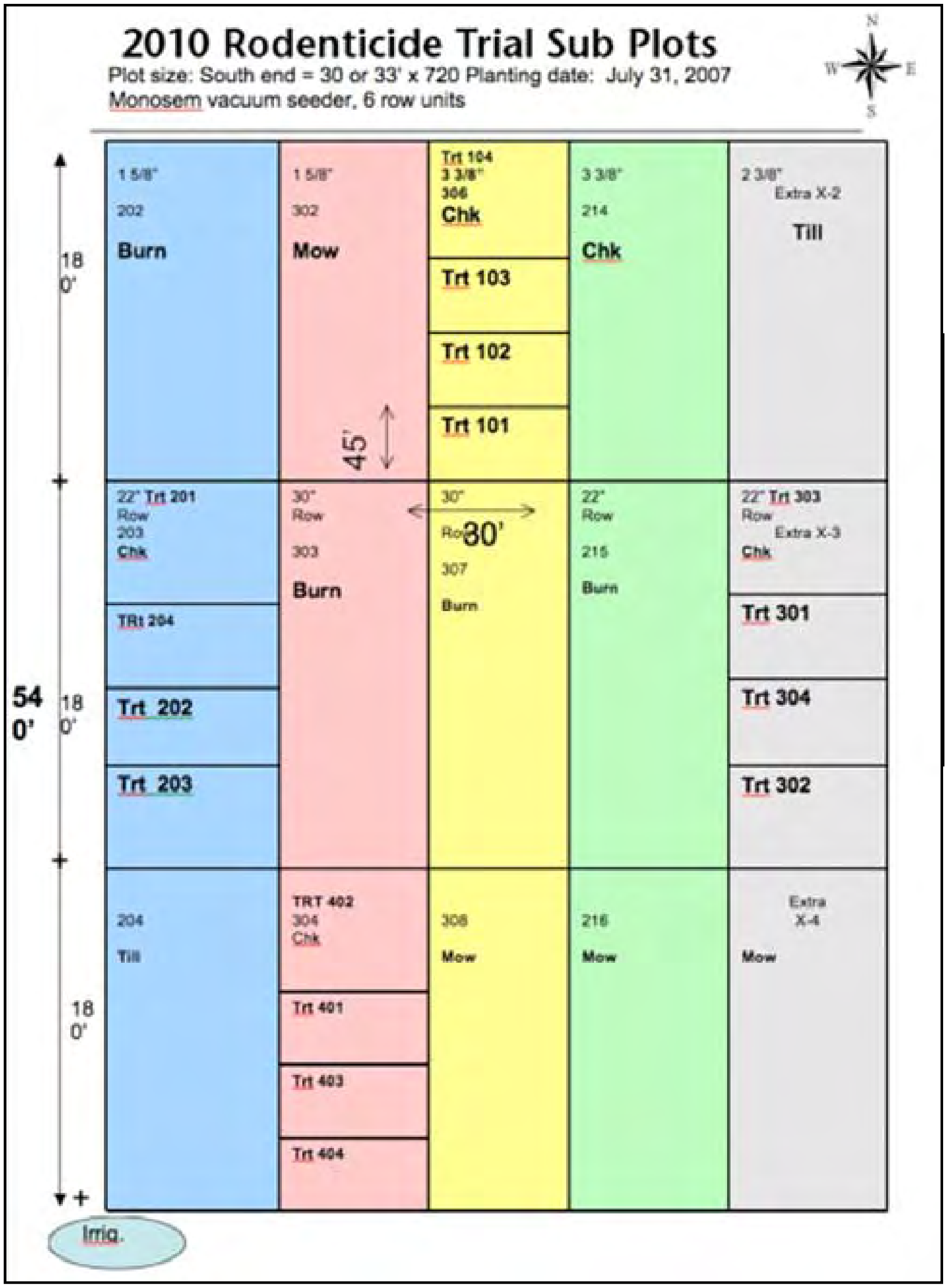


Figure 4. Rodenticide sub plot schematic.

Methods

Following the imposition of the various stubble removal treatments in 2009, we noticed that a side effect of not burning was a population outbreak of voles, which was most pronounced in the untreated plots. This provided us with the opportunity to conduct some simple tests on several rodenticides. We were able to acquire additional research funds from the Washington State Commission on Pesticide Registration and we began a new adventure as amateur rodent vertebrate control specialists.

Plots were established for 4 treatments in February 2010. Plot size was 30 feet in width by 45 feet in length. These plots were established in the untreated control plots of the burning trial as detailed in Figure 4 by using plots 306, 203, X-3, and 402.

On March 8th, 2010 we attempted to establish pre-treatment counts utilizing a Gnawed Carrot Index. In this attempt, carrots were coiled in wire and the tail of the wire pushed down into the ground to hold the carrot in place. After 48 hours, we went back to the plots and tried to take counts on each replicate plot using the following values as our assessment tools.

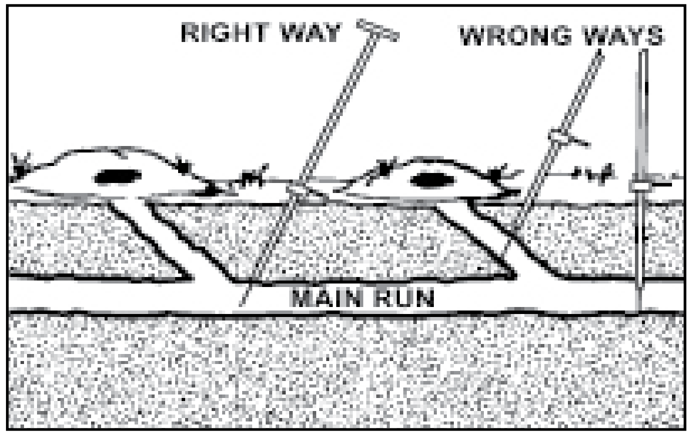
"Gnawed Carrot Index"	
Value	Observation Associated with Value
0	no visible gnawing on carrot
1	slight gnawing 1-10% of carrot surface
2	slight to moderate 15-25% gnawing
3	moderate 25-50% gnawing of surface
4	heavy 50% and better gnawing of surface
5	carrot missing no visible signs left other than the hold-down device licked clean

Unfortunately we determined that the variability among plots was too substantial, therefore we modified our experimental design to utilize the Open Burrow Index as our main evaluation tool. In the Open Burrow Index, all open burrows within a plot were counted on March 10 as a pre-treatment assessment. In this initial assessment it was determined that the mean number of open burrows per plot was 77.37±5.15 (mean±standard error). Following this assessment, all the burrows were plugged with soil. On March 12 a second census of rodent density was taken using the Open Burrow Index. The number of burrows opened was calculated at 37.06±3.40 per plot.

Following this assessment all open burrows were again plugged and treatments were applied to each of 4 replicate plots as indicated in the "Treatments Applied to Plots" table.

The treatments of Rozol (trade name for the rodenticide containing the multiple-feeding anticoagulant, chlorophacinone) and strychnine were deployed into the main runs of the burrows as illustrated above right and were subsequently compared to 4 untreated control plots. Post-treatment assessments were conducted by the Open Burrow Index on March 17, 19, 24, and 26. Results are summarized in Figure 5.

Our results were not significant (p>0.05) and inconclusive. We may attempt these studies again if the opportunity arises.



Deployment of treatments in main runs of rodent burrows.

Treatments Applied to Plots	
Control	Trt 101, 201, 301, 401
Rozol 50 g	Trt 102, 202, 302, 402
Rozol 100 g	Trt 103, 203, 303, 403
Strychnine 5 g	Trt 104, 204, 304, 404

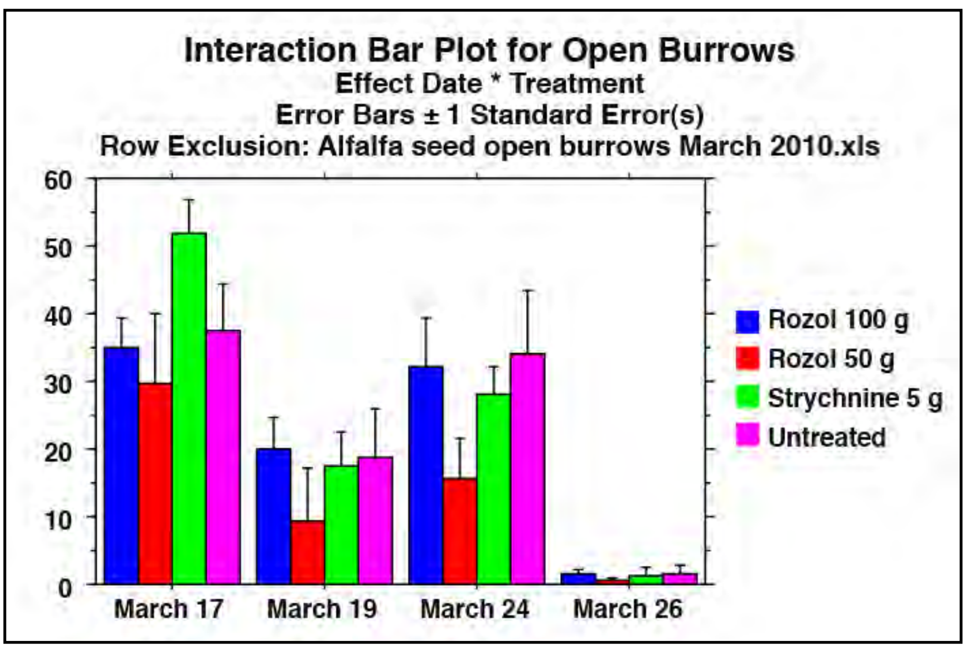


Figure 5. Open Burrows per plot ± SE post treatment by rodenticide

Potential Emissions

Quantifying stubble and calculating mass.

Following the establishment year (2008), the first series of residue removal treatments (winter 2009), and the second cropping year (2009), crop residue yields were collected from all of the plots in 2010 prior to residue treatment application. The data collected were analyzed by analysis of variance and the arithmetic sampled means from the various treatments were compared to the means from the untreated control plots in pairwise *t*-tests to determine if the treatments provided a significant difference compared to the non-treated control.

Utilizing the 2004 report *Quantifying Post-harvest Emissions from Bluegrass Seed Production Field Burning* and the quantities of stubble remaining, we extrapolated the smoke quantities that would potentially have been emitted if our various test plots had all been burned. In the 2004 report, sponsored by the Department of Ecology, authors Johnston and Golob determined that when a burn was conducted at an 87% efficiency on stubble left in a "low-load" grass seed field, the smoke emitted from 1800 lbs. of stubble resulted in 2,881 lbs of carbon dioxide (CO_2), 291 lbs. of carbon monoxide (CO), 18 lbs. of methane (CH_4), 73 lbs. of particulate matter less than 10 microns in diameter (PM10), and 58 lbs. of particulate matter less than 2.5 microns in diameter (PM2.5). We used these values in estimating the potential emissions from our various plot treatments.

Table 9 details the mean square values for the analysis of variance for the field stubble residues and the potential smoke emissions that would result if those residues were burned based on the observed measurements of residues present in February 2010 prior to the application of the second annual mow, till, or burn treatments. The only significant ($p<0.01$) interaction in regards to potential emissions based on these factors is the treatment multiplied by the seed spacing within the row. Treatment, row spacing, and seed spacing and all the additional interactions of these treatments were not significant. Table 10 lists the values and emissions calculations, while Table 11 details the mean square values for the analysis of variance for the field stubble residues and the potential smoke emissions that would result if those residues were burned based on the observed measurements of residues present in February 2010 prior to the application of the second annual mow, till, or burn treatments based on the interaction treatment with seed spacing in the row.

TABLE 9

Effects for Treatment, Row and Seed Spacing and Interactions on Stubble Amounts

Source	*df*	Mean square	*p*-value
Treatment	3	0.52	0.33
Row Spacing	1	1.18	0.11
Seed Spacing	1	1.45	0.08
T x Rs	3	0.38	0.46
T x Ss	3	1.86	0.01
Rs x Ss	1	0.16	0.55
T x Rs x Ss	3	0.19	0.73
Error	38	0.44	

Table 9. ANOVA effects for treatment (burn, mow, till, check), row spacing (22-inch, 30-inch), and seed spacing in row (1-5/8-inch, 3-3/8-inch), and their interactions on the amount of stubble in the plots in February 2010.

TABLE 10

Residue Values and Emissions Calculations

Treatment	Row Spacing	Seed Spacing	Stubble (tons)	CO_2 (lbs)	CO (lbs)	CH_4 (lbs)	$PM_{2.5}$ (lbs)	PM_{10} (lbs)
Burn	22″	1-5/8″	3.46	11,090	1,466	138	199	251
Chk	22″	1-5/8″	3.38	10,848	1,434	135	194	246
Mow	22″	1-5/8″	2.86	9,153	1,210	114	164	208
Till	22″	1-5/8″	3.30	10,557	1,395	131	190	239
Burn	22″	3-3/8″	2.44	7,813	1,032	97	140	177
Chk	22″	3-3/8″	2.79	8,930	1,180	111	160	202
Mow	22″	3-3/8″	3.17	10,146	1,341	126	182	230
Burn	30″	1-5/8″	3.30	10,557	1,395	131	190	239
Chk	30″	1-5/8″	2.38	7,619	1,007	95	137	173
Mow	30″	1-5/8″	2.76	8,847	1,169	110	159	201
Till	30″	1-5/8″	2.24	10,364	1,370	129	186	235
Burn	30″	3-3/8″	2.24	7,167	947	89	129	163
Chk	30″	3-3/8″	2.50	8,015	1,059	99	144	182
Mow	30″	3-3/8″	3.65	11,688	1,546	145	210	265
Till	30″	3-3/8″	2.39	7,652	1,011	95	137	174

Table 10. Mean values for field residues (tons/acre) in plots in February 2010 following a prior winter (2009) treatment by burning, tilling, mowing, or untreated, and a production season, and the calculated emissions (lbs/acre) that would be produced by these residues if these plots were burned in February 2010.

TABLE 11

Effects and Interactions for Treatment and Seed Spacing

Source	*df*	Mean square	*p*-value
Treatment	3	0.45	0.39
Seed Spacing	1	1.48	0.07
T x Ss	3	1.73	0.01
Error	46	0.43	

Table 11. ANOVA effects for treatment (burn, mow, till, check) and seed spacing in row (1-5/8″, 3-3/8″) and their interactions.

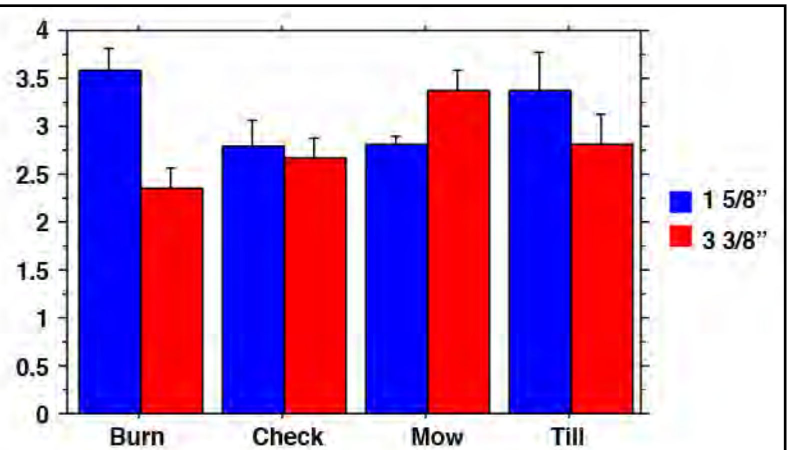


Figure 6. Interaction of treatment with seed spacing in row for field residues in tons per acre based on the observed measurements of residues present in February 2010 prior to the application of the second annual mow, till, or burn treatments.

Conclusion

Burning the field residues of alfalfa fields has empirically proven to provide suppression of specific weeds, insects, and diseases. Manipulation of row spacing and seed spacing within the row had significant effects on seed yields during the establishment year of this study but these effects were overwhelmed by effects of the field stubble residue management treatments, i.e., burning, mowing, tilling, or doing nothing (untreated control). Yield results from both 2009 and 2010 demonstrate that burning of the field stubble and other residue resulted in significantly ($p<0.05$) greater seed yields compared to mowing, tilling, or leaving the residues untreated.

Arthropod abundance was completely unaffected by row spacing and seed spacing within the row. Of the arthropod populations that were quantified during this experiment, only the adult overwintering Lygus bug populations were reduced in the burn and till plots compared to the untreated control. These populations were quite low, but these Lygus are the individuals in the population that serve as the foundation for the subsequent summer's populations of Lygus. Over a large scale, this reduction in Lygus abundance might have an impact on the regional population of Lygus bugs.

White mold sclerotia were significantly ($p<0.05$) reduced in the burned plots compared to the unburned plots. Tilling and mowing had no impact on the abundance of sclerotia. In 2010, the burn treatment also significantly ($p<0.05$) decreased the viability of the sclerotia compared to the untreated control. Burning also significantly favored the colonization of sclerotia by *Fusarium acuminatum*. This fungi is accomplishing biological suppression of the sclerotia, but is not a commercially viable suppression agent as it may contribute to other disease problems. None of the alternative stubble management strategies showed increased benefits for controlling Sclerotinia rot above and beyond the burn treatment.

The abundance of prickly lettuce was largely unaffected by the stubble residue management programs but it was readily controlled by a standard grower herbicide application program, indicating no interaction between the herbicide simazine and the various residue management programs. However with another weed species, Western salsify, there was an interaction between the residue management programs and simazine application: in the areas with herbicide applied, burning and tilling significantly reduced the abundance of Western salsify compared to the untreated control. In the herbicide-free (tarped) areas, the burning and tilling treatments also had a significantly ($p<0.05$) lower population of Western salsify than the control plot. Burning alone was statistically equal to burning plus simazine and was statistically superior to the application of simazine to the untrteated plots and the mowed plots.

Weed seed germination viability was significantly ($p<0.05$) reduced for the three species of weeds tested if the seeds were placed on the soil surface. However this treatment effect was lost when the weed seeds were placed beneath 2.5 cm of soil and litter.

Rodent survivorship was an unforeseen consequence of leaving the field stubble residue extant. We speculate that the residue provided food and shelter for the resident rodent population. Mowing and tilling appeared to reduce rodent populations at the observational level, as did burning. This demonstrates that if growers were restricted from burning, additional costs might be incurred for rodent control if field residues are permitted to build up.

Results from Analysis of Variance (ANOVA) demonstrate the row spacing at 22 or 30 inches was not a significant factor in field residues and subsequently emissions once a stand was established and treated for 2 years. However, seed spacing within the row was slightly significant (p<0.07) and there was a highly significant (p<0.01) interaction between the residue treatments and seed spacing within the row. In the untreated check, tilling, and mowing treatments, the 1-5/8-inch seed spacing within the row resulted in greater residues in tons per acre. This was highly significant in the burn plots.

Figure 7 graphically represents the mean value ± a standard error of the mean for the number of pounds of field residue present per pound of seed produced in each treatment in 2010. Burning annually reduced the variability of residue present in the field and added some level of production certainty. This graph demonstrates that from a production standpoint the treatment benefit gained from burning would likely be lost within a single season thus diminishing the successful adoption of burning every other year instead of burning annually.

Burning has been an efficient tool for managing field stubble residue and we have provided evidence of some pest control benefits of field burning. With industry support, we will pursue the economics of this practice. As mentioned in the introduction, the crops to which alfalfa seed growers in the Walla Walla Valley can rotate are limited. Given this fact, burning will continue to play a role in enhancing alfalfa seed production in the Walla Walla Valley.

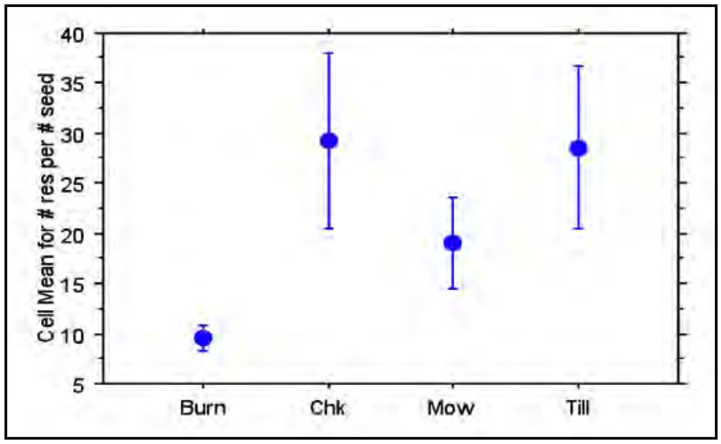


Figure 7. Mean value ± a standard error of the mean for the number of pounds of field residue present per pound of seed produced in each treatment in 2010.