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EXAMINING POSSIBLE BENEFITS OF PLANT GROWTH REGULATOR MIXTURES IN TALL FESCUE SEED CROPS

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Introduction

Tall fescue is the most widely grown grass seed crop in Oregon. Like other cool-season grasses, tall fescue produces only a fraction of its potential seed yield. In a study conducted by Young et al. (1998), tall fescue crops produced 37 to 53% of potential seed yield under Oregon conditions. Lodging of the crop during flowering and seed shattering are two primary factors limiting seed yield. Lodging reduces seed yield in tall fescue by as much as 31%, compared to a crop that is artificially supported in the upright position (Griffith, 2000).

Two stem-shortening growth regulators—chlormequat chloride (CCC; trade name Cyclocel) and trinexapac-ethyl (TE, trade name Palisade EC)—enhance seed yield in forage grasses. These products act by blocking gibberellic acid (GA) biosynthesis.

Since being developed as a plant growth regulator (PGR), TE has been widely adopted for use as a lodging control agent in grass seed production globally. Studies conducted in western Oregon have recently shown reductions in lodging (ranging from 46 to 62%), a result of stem shortening, when TE was applied to tall fescue at 1.5 pt/acre and 3.0 pt/acre, respectively (Chastain et al., 2015).

Prior to the development of TE, CCC was used commercially in ryegrass seed crops in New Zealand, where it produced seed yield increases of 34 to 44% (Hampton, 1986). Since TE produces higher seed yield responses than CCC, rapid grower adoption of TE resulted. Although both CCC and TE are GA inhibitors, CCC acts in the early steps of GA biosynthesis, while TE acts late in the pathway.

Recent studies in perennial ryegrass and orchardgrass have investigated whether combinations of PGRs that act at different points in the GA pathway have additive effects on seed yield. For example, when a tank-mix of CCC and TE was applied to orchardgrass, seed yields were increased by 84% across five New Zealand experiments (Rolston et al., 2014).

There is no information available locally or in international literature on stem-shortening effects or seed yield responses of tall fescue crops to CCC or mixes of CCC and TE plant growth regulators. The objectives of this study were to determine the effects of CCC and TE + CCC combinations on seed yield, seed weight, seed number, percent lodging, above-ground biomass, crop height, and harvest index in tall fescue seed crops.

Materials and Methods

In 2016, field trials were conducted on four commercial first-year tall fescue seed fields, located across the Willamette Valley. Each field was spring planted in the previous year, and none of the fields received spring irrigation prior to harvest. The experimental design for the trials was a randomized complete block with three replications. Treatments included the following PGR products and application rates:

- Untreated control (No PGR)
- 1.5 pt TE/acre applied at BBCH 32–37 (two nodes to early flag leaf emergence)
- 1.34 lb CCC/acre applied at BBCH 32–37
- 1.5 pt TE/acre + 0.67 lb CCC/acre applied at BBCH 32–37
- 1.5 pt TE/acre + 1.34 lb CCC/acre applied at BBCH 32–37
- 0.75 pt TE/acre + 0.67 lb CCC/acre applied at BBCH 32–37

Plot size was approximately 28 feet x 300 feet. Each trial was fertilized by the grower at standard nitrogen rates, and routine fungicide sprays were applied to manage stem rust. Above-ground biomass samples were taken from each plot near crop maturity, and dry weight (biomass) of the standing crop was determined. The length of stems was measured for each treatment at harvest maturity to determine crop height. Lodging ratings were taken prior to swathing and harvest.

Seed was harvested with grower swather and combine equipment, and seed yield was determined with a weight wagon. Harvested seed was cleaned to determine clean seed yield. Seed weight was determined by counting two 1,000-seed samples with an electronic seed counter and weighing these samples on a laboratory balance. Harvest index, the ratio of seed yield to above-ground biomass, was also determined.

Results and Discussion

All treatments that contained TE reduced lodging in tall fescue, in comparison with the untreated control (Table 1). The control treatment was mostly lodged (93%) across the trials. Reduction in lodging from TE alone was large (73%) with the 1.5 pt/acre rate. However, CCC alone was inconsistent and weak in its effect on lodging. When CCC was added to mixtures containing 1.5 pt/acre TE, lodging tended to be reduced slightly more than with TE alone, but the difference was not significant. When the amount of TE in the TE + CCC mix was reduced to 0.75 pt/acre, reduction in lodging was not as large (22%).

Lodging reduction with TE across study sites was made possible by reduction in canopy height (stem length), as compared to the untreated control (Table 2). There was no difference in above-ground biomass between any treatments at any site.

Seed yields were variable, but were higher than the 10-year average yield of 1,535 lb/acre for the Willamette Valley.

Application of TE consistently controlled lodging in tall fescue in all four cultivars in these studies. There was a positive effect of TE and mixes of TE + CCC on seed yield at all locations. The 1.5 pt/acre TE treatment increased seed yield by 23.9%.

The use of CCC alone or in mixtures with TE did not influence seed yield (Table 2). Results indicated that PGR mixtures provided no additional benefit over the 1.5 pt/acre TE treatment.

Seed weight was not affected by any of the PGR treatments and did not contribute to the increased seed yield observed when TE was applied. Seed number was significantly increased by TE, but not by CCC, at three of the four study sites. The increase in seed yield with TE is likely attributable to this increase in seed number.

Harvest index provides a measure of how grass seed crop management impacts partitioning of seed in relation to total above-ground biomass production. Harvest index was not significantly affected by TE or CCC application, either when applied alone or in a mixture (Table 2).

The results of the first year of this 2-year study indicate that adding CCC to TE applications does not have any economic advantage. This work will be repeated in 2017 on the same four commercial tall fescue fields to examine the results of these treatments on second-year stands.

Table 1. Effect of trinexapac-ethyl (TE) and chlormequat chloride (CCC) mixes on lodging in tall fescue crops.[1]

	% lodging			
	Washington County	Polk County	Linn County	Benton County
Untreated control	80.0 c	96.7 c	100.0 c	96.7 c
TE 1.5 pt/a	23.3 a	20.0 a	46.7 ab	20.0 a
CCC 1.34 lb ai/a	76.7 c	90.0 b	100.0 c	90.0 b
TE 1.5 pt/a + CCC 0.67 lb ai/a	20.0 a	20.0 a	30.0 a	20.0 a
TE 1.5 pt/a + CCC 1.43 lb ai/a	20.0 a	20.0 a	26.7 a	20.0 a
TE 0.75 pt/a + CCC 0.67 lb ai/a	44.3 b	23.3 a	66.7 b	23.3 a

[1]Numbers followed by the same letters are not significantly different by Fisher's protected LSD values ($P = 0.05$).

Table 2. Effect of trinexapac-ethyl (TE) and chlormequat chloride (CCC) mixes on seed yield, seed weight, above-ground biomass, canopy height, seed number, and harvest index in tall fescue crops.[1]

Treatment	Yield	Seed weight	Biomass	Height	Seed number	H.I.[2]
	---------- Washington County ----------					
	(lb/a)	(mg/seed)	(ton/a)	(cm)	(seeds/m^2)	(%)
Untreated control	1,492 a	2.431	9.45	129.0 b	68,896 a	7.9
TE 1.5 pt/a	1,913 b	2.422	10.17	107.4 a	88,571 b	9.6
CCC 1.34 lb ai/a	1,575 a	2.347	11.61	126.1 b	75,204 a	6.9
TE 1.5 pt/a + CCC 0.67 lb ai/a	1,969 b	2.392	9.96	105.7 a	92,146 b	10.4
TE 1.5 pt/a + CCC 1.43 lb ai/a	2,066 b	2.365	10.94	106.2 a	98,021 b	9.6
TE 0.75 pt/a + CCC 0.67 lb ai/a	1,961 b	2.362	10.43	108.5 a	93,101 b	9.5
	---------- Polk County ----------					
Treatment	Yield	Seed weight	Biomass	Height	Seed number	H.I.[2]
	(lb/a)	(mg/seed)	(ton/a)	(cm)	(seeds/m^2)	(%)
Untreated control	2,422 a	2.572	9.13	109.1 c	105,596 a	13.7
TE 1.5 pt/a	3,011 b	2.529	9.23	84.8 a	133,679 c	16.3
CCC 1.34 lb ai/a	2,544 a	2.497	9.77	108.0 c	114,179 ab	13.2
TE 1.5 pt/a + CCC 0.67 lb ai/a	3,224 b	2.568	10.41	88.9 ab	140,849 c	15.6
TE 1.5 pt/a + CCC 1.43 lb ai/a	3,225 b	2.512	9.84	82.3 a	143,918 c	16.4
TE 0.75 pt/a + CCC 0.67 lb ai/a	2,995 b	2.567	9.73	92.9 b	130,754 bc	15.4
	---------- Linn County ----------					
Treatment	Yield	Seed weight	Biomass	Height	Seed number	H.I.[2]
	(lb/a)	(mg/seed)	(ton/a)	(cm)	(seeds/m^2)	(%)
Untreated control	2,183 a	2.536	11.32	128.1 c	96,496	9.8
TE 1.5 pt/a	2,630 bc	2.518	13.51	103.0 ab	117,150	10.0
CCC 1.34 lb ai/a	2,348 ab	2.507	13.69	122.8 c	104,973	8.6
TE 1.5 pt/a + CCC 0.67 lb ai/a	2,666 c	2.582	14.77	104.3 ab	115,837	9.1
TE 1.5 pt/a + CCC 1.43 lb ai/a	2,593 bc	2.555	11.32	96.2 a	113,875	11.5
TE 0.75 pt/a + CCC 0.67 lb ai/a	2,516 bc	2.529	13.90	107.3 b	111,529	9.2
	---------- Benton County ----------					
Treatment	Yield	Seed weight	Biomass	Height	Seed number	H.I.[2]
	(lb/a)	(mg/seed)	(ton/a)	(cm)	(seeds/m^2)	(%)
Untreated control	2,033 a	2.363	13.21	133.2 b	96,538 a	7.7
TE 1.5 pt/a	2,490 c	2.355	12.92	110.4 a	118,532 c	9.7
CCC 1.34 lb ai/a	2,082 a	2.357	12.63	129.4 b	99,047 a	8.4
TE 1.5 pt/a + CCC 0.67 lb ai/a	2,576 c	2.375	12.54	108.9 a	121,692 c	10.3
TE 1.5 pt/a + CCC 1.43 lb ai/a	2,476 bc	2.378	14.40	104.4 a	116,814 bc	8.7
TE 0.75 pt/a + CCC 0.67 lb ai/a	2,356 b	2.367	12.27	112.8 a	111,651 b	9.7

[1]Numbers followed by the same letters are not significantly different by Fisher's protected LSD values (*P* = 0.05).
[2]H.I. = harvest index

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INCIDENCE OF VIRUSES IN FESCUE (*FESTUCA* SPP.) SEED PRODUCTION FIELDS IN THE WILLAMETTE VALLEY, 2016

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Introduction

The Willamette Valley is the primary production area for grasses grown for seed in the United States. In 2015, Oregon grass seed growers produced 212.8 million pounds of fescue seed, valued at $163.5 million, on 152,000 acres (Anderson, 2015).

Fescue plants are known to be vulnerable to two viruses, Barley yellow dwarf virus (BYDV-MAV and BYDV-PAV) and Cereal yellow dwarf virus (CYDV-RPV). Both are now endemic to wheat and barley fields throughout the Willamette Valley. Although these viruses can be economically devastating in oats, barley, and wheat, CYDV-RPV (genus *Polerovirus*), BYDV-MAV, and BYDV-PAV (both of genus *Luteovirus*) can persist for years in many perennial grass hosts. Symptoms include yellowing or reddening of leaf tips, a reduction in root mass, and subsequent stunting of plant growth. However, in some cases, infected plants express no obvious visible symptoms (Watson and Mulligan, 1960; Catherall, 1966; Miller et al., 2002).

CYDV-RPV, BYDV-MAV, and BYDV-PAV are exclusively aphid transmitted, and many grasses and cereals are hosts for these viruses (D'Arcy and Domier, 2000). To test for the presence of virus in collected plant samples, an enzyme-linked immunosorbent assay (ELISA) was used. The ELISA method is a sensitive and reliable serological laboratory test, which provides a more accurate determination of the presence of viruses in Willamette Valley fescue fields than relying on visual symptoms alone.

Methods and Materials

Fescue sampling

To determine the occurrence of these viruses, leaf samples were collected from 16 fescue seed production fields located throughout the Willamette Valley. Fescue fields sampled were predominantly forage- and turf-type tall fescue (*Festuca arundinacea* L.). One field each of Chewings fescue (*Festuca rubra* L. subsp. *commutata*) and strong creeping red fescue (*Festuca rubra* L. subsp. *rubra*) was sampled. Both of these are fine fescue types. The age of fescue seed production fields surveyed ranged from 2 to 20 years.

The fescue fields were sampled in April and May of 2016. Fifteen samples were collected per field, with seven of the samples collected along two transects of a V pattern and the other eight samples collected based on visual symptoms indicative of a possible virus infection. Suspect samples were collected from the periphery of bare and sparsely populated areas in the field or areas where plants displayed yellow or reddish leaf tips.

ELISA testing

Samples were collected and placed into 48 deep well plates (VWR International LLC, Radnor, PA). The plates were placed on ice after collection and then stored at 4°C until processing. Samples were homogenized in phosphate-buffered saline solution that contained 2% PVP-44, 0.1% nonfat skim milk powder, and 0.05% Tween-20 using a Meku leaf juice press (Meku Erich Pollähne GmbH, Leopoldshoehe, Germany). Each sample was tested for the presence of three viruses (BYDV-MAV, BYDV-PAV, and CYDV-RPV) by ELISA (enzyme-linked immunosorbent assay), resulting in 45 separate readings per field. The ELISA kits (Agdia, Elkhart, IN) were used according to the manufacturer's instructions. After the substrate was added, the sample plates were stored at room temperature overnight and then read with an ELx808 plate reader (BioTek, Winooski, VT) at an absorbance of λ 405 nm.

Each sample plate had two blank wells containing grinding buffer in lieu of samples. The values of these wells were averaged to obtain the Blank Value of that plate. Samples were considered positive if their absorbance reading was greater than three times the Blank Absorbance Value. Evaluations for each virus consisted of two parameters: the percentage of virus-positive fields (100 x [number of fields positive/total number of fields tested]) and the incidence of disease, which was based on the number of positive samples in each field. Disease incidence ratings were as follows: one or two positives = mild; three to five positives = moderate; and six or more positives = severe.

Results and Discussion

In 2016, virus surveys revealed that all 16 fescue seed production fields tested negative for BYDV-MAV. However, 94% of the fields tested positive for

Table 1. Results of 2016 fescue seed production virus surveys.

Virus	------------- Number of fields with indicated levels of infection[1] -------------				% of infected fields
	0 samples infected	Mild infection	Moderate infection	Severe infection	
BYDV-MAV	16	0	0	0	0%
BYDV-PAV	1	3	1	11	94%
CYDV-RPV	2	1	3	10	88%

[1]Disease incidence: mild infection = one or two positive samples; moderate infection = three to five positive samples; severe infection > five positive samples

BYDV-PAV, 88% tested positive for CYDV-RPV, and many fields had a high incidence level of both viruses (Table 1). Interestingly, all of the fescue fields surveyed tested positive for either BYDV-PAV, CYDV-RPV, or both viral pathogens. In four of the surveyed fields, more than 66% of individual samples tested positive for either BYDV-PAV, CYDV-RPV, or both (Table 2). The strong red creeping fescue field had only one positive sample, and one tall forage fescue field had only two positive samples.

We do not have enough information to explain the wide range of results, but we feel that they need to be investigated further. Previous reports suggest fescue plants are asymptomatic when infected with BYDV and CYDV (Watson and Mulligan, 1960). The data collected from the field survey were examined to determine whether selecting suspected symptomatic plants resulted in a higher frequency of virus-infected plants compared to random plant samples representative of individual fields (Table 3). There were more ELISA-positive samples in the suspected disease samples than in the random samples in the majority of the fields surveyed (12 of 16). In three fields, the random samples had more positive results. Only one field resulted in the same number of virus-infected samples regardless of sampling procedure. The *p* values of the two-tailed t-test for BYDV-PAV and CYDV-RPV were both 0.01, which means we collected more infected samples when selecting plants that appeared symptomatic than when we randomly collected samples from a chosen area. This would indicate that the tall fescue plants were displaying symptoms or that the observed stand thinning was related to virus infection and not to random chance.

Future Research

In October 2016, we planted a virus trial consisting of 9 grass species representing 101 different varieties (Table 4). The purpose of this trial is to observe BYDV and CYDV incidence/severity levels in different varieties and to observe stand persistence over 3 years. The trial includes 22 varieties of fine fescue, 25 varieties of orchardgrass, 28 varieties of perennial ryegrass, 25 varieties of tall fescue, and 1 variety of festulolium. A tall fescue plant infected with BYDV and/or CYDV will be planted into each plot in April 2017, and *Rhopalosiphum padi* (the aphid vector of these viruses) will be introduced into the field twice a month during the summer. Rates of infection will be assessed by the presence of visual symptoms in late spring and summer and by yearly ELISA testing.

Table 2. Number of samples testing positive for BYDV-PAV and CYDV-RPV.[1]

Field number	Fescue type[2]	Samples with BYDV-PAV	Samples with CYDV
1	TTF	7	4
2	TTF	8	11
3	TTF	8	7
4	TTF	8	9
5	TTF	10	13
6	TTF	14	7
7	TTF	5	7
8	FTF	2	3
9	FTF	6	7
10	FTF	14	6
11	FTF	10	5
12	FTF	6	2
13	FTF	15	6
14	FTF	2	0
15	Chewings	0	7
16	Strong red	1	0

[1]Total number of samples tested per field = 15.
[2]Fescue type: TTF = turf tall fescue; FTF = forage tall fescue

Table 3. Comparison of virus-positive samples—symptomatic samples (8) versus random samples (7) collected from 16 fields.

	---------- Positive for BYDV-PAV ----------		--------- Positive for CYDV-RPV --------	
Field number	Symptomatic samples	Representative field samples	Symptomatic samples	Representative field samples
1	4	3	2	2
2	6	2	8	3
3	6	2	6	1
4	6	2	6	3
5	7	3	8	5
6	8	6	6	1
7	5	0	7	0
8	1	1	3	0
9	3	3	3	4
10	7	7	2	4
11	5	5	2	3
12	4	2	2	0
13	8	7	4	2
14	1	1	0	0
15	0	0	6	1
16	1	0	0	0
Sample Σ	72	44	65	29
p value, t-test		0.01		0.01

Table 4. Types of grass in virus trial planted in fall 2016.

	---- Number of entries ----	
Type of grass	Turf type	Forage type
Chewings fescue	6	—
Hard fescue	6	—
Sheep fescue	1	—
Slender creeping red fescue	2	—
Strong creeping red fescue	7	—
Festulolium	—	1
Orchardgrass	—	25
Perennial ryegrass	25	3
Tall fescue	17	8

Conclusion

Survey results indicate that BYDV-PAV and CYDV-RPV exist in fescue fields throughout the Willamette Valley. We have planted a test plot with the hope of identifying varieties that are resistant or tolerant to virus infection or resistant to aphid feeding, because finding resistance to these viruses or their vectors will remain the best management solution. Fields will continue to be monitored in the coming years, with emphasis on examining field infection in different varieties to identify tolerant and resistant cultivars, as well as varieties that possess aphid-aversion qualities that could reduce virus spread. The information gleaned from this project will be used to inform growers of the pervasiveness of these viruses so that they can better manage the risk to production.

Growers must decide whether spraying for aphids is an economically feasible option to help control these viruses. If it is, an aphid flight monitoring system could be beneficial to help growers with timely insecticide application information for preventing the spread of the yellow dwarf viruses.

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AN 11-YEAR HISTORY OF CROP ROTATION INTO NEW PERENNIAL RYEGRASS AND TALL FESCUE

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Introduction

Grass seed production in western Oregon is maturing from an older emphasis on how quickly it was possible to rotate from one grass seed crop to the next to a newer one in which rotational crops themselves are expected to be profitable and provide long-term benefits for future grass seed crops. Benefits from crop rotations may include disruption of the life cycle of pests such as slugs, weeds, diseases, insects, and rodents, along with improved soil fertility, health, and physical properties.

Researchers, advisors, and growers currently have more questions than answers regarding the long-term benefits of specific crop rotation sequences and associated management practices. One approach for improving this situation is to develop an industry-wide census of current crop rotations and then study the relationships between those practices and factors of interest, such as reliability of attempts to establish new grass seed stands, duration of those stands, and prevalence of particular pests before and after rotations from one grass seed crop to the next. We converted an 11-year-long remote-sensing-based record of western Oregon crops into knowledge of complete crop rotation cycles from old grass seed stands to new ones with varying years of intervening crops. The challenges in developing such data have been presented elsewhere (Mueller-Warrant et al., 2015, 2016a, 2016b).

This report focuses on crop rotation patterns in fields transitioning from previous grass seed crops to new stands of perennial ryegrass or tall fescue. Our primary objectives were to: (1) measure the distribution of years spent growing rotational crops or fallow between successive grass seed stands, and (2) identify the primary rotational sequences used during each period.

Materials and Methods

Through ground-truth, drive-by surveys of several thousand fields per year, we identified crop kind and establishment status and were able to convert satellite imagery and aerial photographs into classifications of 19 annually disturbed crops, 20 established perennial crops, 13 forest types, and 5 urban development levels. Tests for consistency of year-to-year transitions from 2004 to 2014 refined land-use classification during conversion of 11 individual-year data sets into stand duration measurements and crop rotation sequences. The most typical error was omission of fields that should have been recognized as intervening rotational crops grown between older and newer grass seed stands.

Results and Discussion

Length of crop rotation cycles

The length of crop rotations was measured from the final year of a previous grass seed crop to the first harvest of a fully established new stand of perennial ryegrass (not the harvest 9 months after fall planting). The most common length was 3 years, with the second, third, fourth, and fifth most common intervals being 6+, 4, 2, and 5 years (Table 1). Rotational periods of

Table 1. General properties of crop rotations from final year of previous grass seed crop to first fully established year of new perennial ryegrass.

Years from final harvest of previous grass seed crop to established stand of perennial ryegrass	Estimated number of fields	Total area	Years available for intervening crops	Number of most common rotations needed to cover one-half of fields
		(acres)		
2	187	12,543	0	1.16
3	287	20,037	1	2.45
4	228	14,941	2	6.86
5	70	4,760	3	19.0
≥6	284	18,834	4+	21.3
All cases	1,056	71,114	—	—

either 3 years or 6+ years were each approximately four times as common as those of 5 years. Fields with only 2 years from established old stands to established new stands represented replanting of the same variety. New perennial ryegrass stands were fall planted an average of 8.6 times as often as they were spring planted. The total area that underwent full crop rotation from one grass seed stand to the next was 71,114 acres, equaling 54% of the average area reported in perennial ryegrass seed production over the period from 2004 to 2014 (Anderson and Young, 2014). There were large changes in area devoted to perennial ryegrass seed production over this period, with the 91,531-acre minimum in 2010 being only 47% of the 192,867-acre maximum in 2005.

The most common length of time for crop rotations into fully established new stands of tall fescue was 6+ years, with the second, third, fourth, and fifth most common intervals being 4, 3, 2, and 5 years (Table 2). Rotational periods of 3, 4, or 6+ years were each approximately 2.2 times as common as those of 5 years. New tall fescue stands were spring planted an average of 1.4 times as often as they were fall planted. Total area identified as undergoing full crop rotation cycles from one grass seed stand to the next was 69,543 acres, equaling 49% of the average area reported in tall fescue seed production. There were large changes in area devoted to tall fescue over these years, with the 106,474-acre minimum in 2011 being only 61% of the 174,506-acre maximum in 2008.

Crop rotation distribution patterns

One way to simultaneously examine crop rotation length, numbers of unique crop rotations present in each length rotation, and varying area associated with each rotation was to calculate how many different types of the most common rotations would be needed to cover one-half of the field area present in each of those rotation periods (Table 1). For the shortest possible rotation (immediate planting back to perennial ryegrass with no time for intervening non-grass seed crops), it would take only 1.16 unique rotations to cover 50% of the field area present within all of the 2-year rotations (the single most common rotation plus 16% of fields with the second most common rotation). Crop rotations became more complicated as the number of years for growing intervening crops increased. The exponential increase in the number of rotations necessary to cover half of the field area (on average 2.2 times as many for each additional year of rotation length over a regression base of 1.25 rotations) is a way of expressing this factor.

Several aspects of crop rotation distribution patterns for tall fescue stood out as differing from those for perennial ryegrass (Table 2). For the shortest possible rotation (immediate planting back to tall fescue, with no time for intervening non-grass seed crops), it took 1.81 unique rotations to cover 50% of the field area present within all of the 2-year rotations. The number of required rotations increased an average of 1.8 times over a 2.64 base for each additional year.

The number of rotations required to cover half of the field area for the three shortest crop rotation lengths was higher for tall fescue than for perennial ryegrass, underscoring the greater complexity of challenges facing growers of tall fescue, a slower-to-establish crop that often fails to produce harvestable amounts of seed even when fall planted. A partial list of such challenges includes: (1) competition from summer annual weeds (e.g., sharppoint fluvellin), which may weaken seedling stands of spring-planted tall fescue and force growers to reseed, (2) financial constraints imposed by the

Table 2. General properties of crop rotations from final year of previous grass seed crop to first fully established year of new tall fescue.

Years from final harvest of previous grass seed crop to established stand of tall fescue	Estimated number of fields	Total area	Years available for intervening crops	Number of most common rotations needed to cover one-half of fields
		(acres)		
2	177	11,318	0	1.81
3	249	16,949	1	4.89
4	252	16,534	2	15.0
5	116	7,902	3	22.0
≥6	258	16,838	4+	16.5
All cases	1,052	69,543	—	—

additional year without a harvestable seed crop for spring versus fall planting, (3) greater susceptibility to yield loss when "salvage treatments" of glufosinate are applied to tall fescue compared to perennial ryegrass, and (4) constraints on choice of rotational crops following prior stands of tall fescue due to the use of higher rates of soil-residual herbicides in tall fescue than in perennial ryegrass.

Crop rotations with 2-year periods

Four major crop rotation sequences accounted for 93.9% of the area in which only 2 years elapsed from the last crop of the previous stand to the first fully established (non-seeding year) crop of a new perennial ryegrass stand (Table 3). The most common rotation (2004–2012) was final crop of the old perennial ryegrass stand–fall-planted perennial ryegrass–first

Table 3. Rotations lasting 2 to 4 years from any previous grass seed crop to new stands of established perennial ryegrass.

Crop rotation (Read moving forward in time from left to right)[1]	----- Area covered -----	
	(acres)	(%)
2-year-long rotations ending in fully established perennial ryegrass (EST PR)		
EST PR–fall plant PR–EST PR	5,916	47.2
EST FF–fall plant PR–EST PR	3,505	27.9
AR–fall plant PR–EST PR	1,502	12.0
EST PR–spring plant GS or UNK–EST PR	857	6.8
All other 2-year rotations	766	6.1
3-year-long rotations ending in fully established perennial ryegrass (EST PR)		
EST PR–WW–fall plant PR–EST PR	4,844	24.2
EST PR–winter fallow/UNK summer–fall plant PR–EST PR	4,411	22.0
EST PR–beans–fall plant PR–EST PR	1,899	9.5
EST FF–WW–fall plant PR–EST PR	1,067	5.3
EST TF–WW–fall plant PR–EST PR	867	4.3
EST TF–winter fallow/UNK summer–fall plant PR–EST PR	637	3.2
EST PR–winter fallow/UNK summer–spring plant GS–EST PR	516	2.6
EST bentgrass–winter fallow/UNK summer–fall plant PR–EST PR	462	2.3
EST PR–winter/summer fallow–fall plant PR–EST PR	432	2.2
EST PR–winter/summer fallow–spring plant GS–EST PR	422	2.1
All other 3-year rotations	4,481	22.2
4-year-long rotations ending in fully established perennial ryegrass (EST PR)		
EST PR–WW–WW–fall plant PR–EST PR	2,107	14.1
EST PR–winter fallow/UNK summer–winter fallow/UNK summer–fall plant PR–EST PR	1,843	12.3
EST PR–beans–winter fallow/UNK summer–fall plant PR–EST PR	768	5.1
EST PR–winter fallow/UNK summer–WW–fall plant PR–EST PR	978	6.5
EST TF–WW–WW–fall plant PR–EST PR	746	5.0
EST PR–WW–winter fallow/UNK summer–fall plant PR–EST PR	585	3.9
AR–fall plant clover–EST clover–fall plant PR–EST PR	504	3.4
EST PR–winter fallow/UNK summer–beans–fall plant PR–EST PR	494	3.3
EST PR–winter fallow/UNK summer–winter fallow/UNK summer–spring plant GS–EST PR	393	2.6
EST FF–WW–spring plant PR–fall plant PR–EST PR	343	2.3
EST PR–fall plant clover–EST clover–fall plant PR–EST PR	331	2.2
EST FF–WW–WW–fall plant PR–EST PR	309	2.1
All other 4-year rotations	5,543	37.1

[1]AR = annual ryegrass; EST = established; FF = fine fescue; GS = grass seed; PR = perennial ryegrass; UNK = unknown crop; WW = winter wheat

post-establishment crop of the new perennial ryegrass stand. This rotation accounted for 47.2% of the area and corresponded to seed certification rules for planting fields back to the same variety previously grown. The second most common rotation, used on 27.9% of the area, was established fine fescue–fall-plant perennial ryegrass–established stand of perennial ryegrass. Two general traits of fine fescue enhance the feasibility of a rapid transition from established fine fescue to perennial ryegrass: (1) tillage is highly effective in destroying fine fescue plants, and (2) seedling fine fescue generally fails to flower the first spring after fall planting and so would not contaminate the first seed harvest of a new perennial ryegrass planting.

Five major crop rotation sequences accounted for 89.2% of the area in which only 2 years elapsed from the last crop of the previous stand to the first fully established crop of a new tall fescue stand (Table 4). The most common rotation was final crop of the old tall fescue stand–spring-planted grass seed–first post-establishment seed crop of the new tall fescue stand (harvested in 2006 to 2014). This rotation accounted for 29.2% of the area. The second most common rotation, used on 22.5% of the area, was old tall fescue–fall-planted tall fescue–established new tall fescue. This rotation was similar to the first one, differing mainly in the existence of a modest chance of producing harvestable seed the first summer after planting.

Crop rotations with 3-year periods

The next longer rotations were defined by the presence of a single intervening (non-grass seed) crop prior to planting of perennial ryegrass. When 3-year rotations from any kind of grass seed crop to established stands of perennial ryegrass were examined, the 10 most common ways to make these transitions accounted for 77.8% of the area (Table 3). The single most common rotation, covering 24.2% of the area, was established perennial ryegrass–winter wheat/fall-planted perennial ryegrass–established perennial ryegrass. Winter wheat was used as the first crop following termination of grass seed stands on 34.8% of the area. The winter fallow/unknown summer crop class was used as an intervening crop in five rotations covering 31.7% of the area. The winter fallow/unknown summer crop category was a diverse class that included multiple crops. Its primary common feature was the openness of the ground during the preceding winter. This category likely included some irrigated annual crops, other dryland crops, and some perennials whose winter growth was limited. This class possessed a strong tendency to overlap with established clover, fall-planted clover, beans, flowers, field peas, and new planting alfalfa. Only two of the 21 most common rotations used spring planting instead of fall planting for establishment of new perennial ryegrass stands, for a total of 18.9 times as much fall planting as spring planting.

When 3-year rotations from any kind of grass seed crop into new stands of tall fescue were examined, the 12 most common ways to make these transitions accounted for 76.3% of the area (Table 4). Spring planting was used 2.61 times as often as fall planting in establishing the new stands of tall fescue in 3-year-long rotations. The single most common rotation, present on 14.1% of the area, was annual ryegrass–winter fallow/unknown summer crop–spring-planted grass seed–established tall fescue. Winter wheat was used as the intervening crop on a total of 17.5% of the area when transitioning to new tall fescue stands in 3-year-long rotations. This was roughly half of its use in similar-length rotations into perennial ryegrass. Interestingly, only 26% of the area with a winter wheat intervening crop used spring planting of the new tall fescue crop, in contrast to 78% of the area over all of the 3-year-long rotations.

Crop rotations with 4-year or longer periods

The 4-year rotations into perennial ryegrass with 2 years for alternatives to grass seed were more diverse than the 3-year rotations. The 12 most common 4-year rotations accounted for only 62.9% of the area (Table 3). Winter wheat was grown for 2 years in rotations between grass seed crops on 21.1% of the area. It was also grown as just the first or second intervening crop on 9% and 6.5% of the area, respectively. Grower preferences for winter wheat as first, second, or both intervening crops in 4-year rotations may indicate varying needs to improve control of grass weeds through selection of clover, beans, unknown summer crops, or fallow rather than winter wheat. Fall-planted perennial ryegrass was used twice in a row in two rotations on a total of 3.9% of the area, representing the all-too-common experience of failing in first attempts to establish new perennial ryegrass stands.

The 10 most common of the 4-year rotations into tall fescue accounted for only 40.0% of the area (Table 4). Established tall fescue, established perennial ryegrass, and annual ryegrass occurred as starting crops on 28.4%, 14.6%, and 11.7% of the area, respectively. Multiple rotations featured two consecutive attempts to establish tall fescue, implying failure on the first try.

Table 4. Rotations lasting 2 to 4 years from any previous grass seed crop to new stands of established tall fescue.

Crop rotation (Read moving forward in time from left to right)[1]	---- Area covered ----	
	(acres)	(%)
2-year-long rotations ending in fully established tall fescue (EST TF)		
EST TF–spring plant GS–EST TF	3,300	29.2
EST TF–fall plant TF–EST TF	2,547	22.5
AR–fall plant TF–EST TF	2,238	19.8
AR–spring plant GS–EST TF	1,465	12.9
EST PR–spring plant GS–EST TF	543	4.8
All other 2-year rotations	1,230	10.8
3-year-long rotations ending in fully established TF (EST TF)		
AR–winter fallow/UNK summer–spring plant GS–EST TF	2396	14.1
EST TF–winter fallow/UNK summer–spring plant GS–EST TF	1949	11.5
EST TF–WW–fall plant TF–EST TF	1704	10.1
EST PR–winter fallow/UNK summer–spring plant GS–EST TF	1460	8.6
AR–winter/summer fallow–spring plant GS–EST TF	1623	9.6
EST TF–winter fallow/UNK summer–fall plant TF–EST TF	862	5.1
EST TF–WW–spring plant GS–EST TF	773	4.6
EST PR–winter fallow/UNK summer–fall plant TF–EST TF	499	2.9
EST PR–WW–fall plant TF–EST TF	482	2.8
EST TF–winter/summer fallow–spring plant GS–EST TF	474	2.8
EST TF–fall plant TF–spring plant GS–EST TF	351	2.1
EST PR–winter/summer fallow–spring plant GS–EST TF	343	2.0
All other 3-year rotations	4,034	23.7
4-year-long rotations ending in fully established TF (EST TF)		
EST TF–WW–winter fallow/UNK summer–spring plant GS–EST TF	1,440	8.7
AR–winter fallow/UNK summer–winter fallow/UNK summer–spring plant GS–EST TF	946	5.7
EST PR–winter fallow/UNK summer–winter fallow/UNK summer–spring plant GS–EST TF	995	6.0
EST TF–winter fallow/UNK summer–WW–fall plant TF–EST TF	805	4.9
EST PR–WW–winter fallow/UNK summer–spring plant GS–EST TF	487	2.9
AR–WW–winter fallow/UNK summer–spring plant GS–EST TF	467	2.8
EST PR–winter/summer fallow–winter fallow/UNK summer–spring plant GS–EST TF	462	2.8
EST TF–winter/summer fallow–spring plant GS–spring plant GS–EST TF	403	2.4
EST TF–WW–WW–fall plant TF–EST TF	390	2.4
EST TF–winter fallow/UNK summer–winter fallow/UNK summer–spring plant GS–EST TF	373	2.3
All other 4-year rotations	9,769	60.0

[1]AR = annual ryegrass; EST = established; FF = fine fescue; GS = grass seed; PR = perennial ryegrass; UNK = unknown crop; WW = winter wheat

Winter wheat was the single most common intervening crop in 5-year-long rotations leading into new stands of both perennial ryegrass and tall fescue. Included in the longer rotations were numerous cases in which attempts to establish new stands of perennial ryegrass or tall fescue apparently failed in one year and were repeated in the next year. The diversity of cropping sequences present in the longer period rotations likely indicates that growers have yet to decide on the best sequences.

Summary

Growers choose intervening rotational crops non-randomly, presumably anticipating a mixture of benefits ranging from income to reduced populations of troublesome pests.

Fall planting dominated new perennial ryegrass stands regardless of the length of rotation period out of grass seed production. For tall fescue, spring planting was preferred in general over fall planting. However, rotations using winter wheat as the final intervening crop deviated from this pattern, showing a modest preference for fall planting.

Winter wheat was the most common intervening crop in rotations into new stands of perennial ryegrass. In rotations into new stands of tall fescue, unknown summer annuals were the most common intervening crop when either 1 or 4+ years were available for production of intervening crops. Winter wheat was the most common intervening crop when either 2 or 3 years were available.

The full set of crop rotation patterns available for each specific length of time between consecutive grass seed stands rapidly increased in complexity with the number of intervening years. In crop rotations ranging in length from 2 to 5 years, there would be at least 2, 3, 7, and 19 cropping sequences of greatest importance for rotations into new perennial ryegrass, and 2, 5, 15, and 22 sequences going into tall fescue.

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EXPLORING ALTERNATIVE HERBICIDES FOR ROW CREATION IN VOLUNTEER ANNUAL RYEGRASS FIELDS TO BE USED FOR SEED PRODUCTION

C.S. Sullivan, D.W. Curtis, A.G. Hulting, and C.A. Mallory-Smith

Introduction

In addition to row spraying at planting in annual ryegrass (ARG) seed fields, Axiom DF (flufenacet + metribuzin) herbicide is used in Oregon to create rows in volunteer ARG seed production fields. Row creation in volunteer stands has previously been shown to be an effective management practice for improving yields (Young et al., 1998; Silberstein et al., 2000). Thinning the stand reduces competition between plants and results in higher seed yields. Growers in the Willamette Valley have successfully used Axiom DF and/or glyphosate to accomplish row creation in volunteer stands; however, the options for effective herbicides are limited.

Since Axiom DF herbicide is used for weed management in ARG, perennial ryegrass, tall fescue, and wheat production, OSU researchers and the grass seed industry are concerned about additional continuous and widespread use of Axiom DF for row creation. Suspected resistance of ARG to Axiom DF has developed in both field crops and orchards in the Willamette Valley. In order to maintain Axiom as an effective herbicide in field crop production, a need exists to identify alternative herbicides for row spraying purposes. The objective of this study was to evaluate several herbicide products to determine row-creation utility in ARG based on crop safety, effective row formation, and seed yield.

Materials and Methods

Two field trials were established during the fall of 2015 in Linn County. Both fields were volunteer 'Gulf' ARG fields; one field site was in Dever-Conner, and the other was in East Albany. Experiments were arranged as randomized complete block designs with four replications. Plot size was 5 feet x 30 feet.

A bicycle sprayer was set up to create a 3-inch ARG row by spraying out a 7-inch band using seven nozzles (40 03) mounted to the boom at 10-inch spacing. The treatments were sprayed in volunteer stands of ARG when the plants were approximately 4 inches tall. The ten treatments and application rates are outlined in Table 1. Row spraying and harvest details are outlined in Table 2.

Table 1. Herbicide treatments used for row creation in annual ryegrass seed fields in the fall of 2015. (***Note***: The majority of the listed herbicide treatments are not labeled for annual ryegrass seed production.)

Treatment	Active ingredient	Rate
		(lb ai/a)
Control	—	—
Axiom[1,2]	Flufenacet + metribuzin	0.425
Diuron[1,2]	Diuron	1.0
Makaze	Glyphosate	0.75
Matrix	Rimsulfuron	0.047
Goal + Rely	Oxyfluorfen + glufosinate	0.25 + 0.366
Everest	Flucarbazone	0.0273
Metribuzin	Metribuzin	0.375
Kerb	Pronamide	0.25
Alion[1]	Indaziflam	0.013

[1]Glyphosate was added to this treatment at 0.75 lb ai/a.
[2]Product is labeled for row spraying in ARG seed fields in Oregon.

Table 2. Annual ryegrass row spraying details for Experiment 2 in two volunteer stands in Linn County.

Trial	Spray date	Crop height	Spray width	Swathing date	Harvest date
		------------- (inches) -------------			
East Albany	Nov. 6	3–4	7	June 21	July 7
Dever-Conner	Nov. 10	4	7	June 21	July 8

Results and Discussion

The row creation treatments were evaluated based on control of ARG between the rows (row creation) and percent injury to the crop within the row. At both sites, the majority of treatments were successful in creating rows, except for Everest, which had less than 50% control (Table 3). Metribuzin was on the lower end of ARG control between the rows, with only 80% control.

Crop injury by treatment varied between the sites; overall, crop injury was more pronounced at the Dever-Conner site (Table 3). The Dever-Conner trial was sprayed later than the East Albany site, and it experienced more ponding in the winter of 2015–2016, which may explain the increased crop injury. All treatments with added glyphosate (Axiom, diuron, Alion) had very similar control (90–100%) and crop injury (15–30%).

There were no significant differences in clean seed yields between the treatments at either site, but overall the row spraying treatments yielded 100 to 500 lb/acre more than the untreated controls (Table 3). At the Dever-Conner site, it appears that the treatments with higher crop injury tended to produce higher yields (e.g., crop injury for Matrix = 73%; clean seed yield for Matrix = 966 lb/acre).

Based on the first year of data, row creation in volunteer stands can increase seed yield by at least 100 lb/acre, which can be agronomically significant for the grower.

Conclusions and Future Work

While row creation in volunteer stands is a less commonly used practice than row spraying at planting, several growers see benefit in this practice. This first year of data supports OSU Extension's early work that found significant yield increases when 75% of the volunteer ARG was sprayed out. Two additional trials with the same treatments were established in the fall of 2016, and these will be evaluated throughout the year and taken to harvest in 2017.

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Table 3. Herbicide treatment effects on annual ryegrass control (row creation), crop injury, and clean seed yield at two locations in Linn County, OR.

Treatment	ARG control[1] East Albany	ARG control[1] Dever-Conner	Crop injury[1] East Albany	Crop injury[1] Dever-Conner	Seed yield[2] East Albany	Seed yield[2] Dever-Conner
	(%)				(lb/a)	
Control	0	0	0	0	377 a	464 a
Axiom[3]	89	88	16	30	670 a	878 a
Diuron[3]	94	95	15	11	632 a	672 a
Glyphosate	81	96	11	6	569 a	602 a
Matrix	93	85	25	73	541 a	966 a
Goal + Rely	88	89	15	33	594 a	915 a
Everest	16	48	0	23	538 a	561 a
Metribuzin	80	78	6	25	498 a	612 a
Kerb	89	90	3	39	602 a	813 a
Alion[3]	98	100	15	30	543 a	935 a
LSD (P = 0.1)					156	340
CV					23	38

[1]Percent control and crop injury evaluated January 27, 2016 at East Albany and April 15, 2016 at Dever-Conner.
[2]Means followed by the same letter within the same column are not significantly different at LSD (P = 0.1).
[3]Glyphosate was added to this treatment.

EXPLORING ALTERNATIVE HERBICIDES FOR ROW SPRAYING AT PLANTING IN NEW ANNUAL RYEGRASS SEED PRODUCTION FIELDS

C.S. Sullivan, D.W. Curtis, A.G. Hulting, and C.A. Mallory-Smith

Introduction

Row spraying annual ryegrass (ARG) at planting is a useful management tool for growers; however, the options for effective herbicides are very limited. Axiom DF (flufenacet + metribuzin) herbicide is commonly used in Oregon to maintain rows in ARG seed production fields. Estimates indicate that 40% of the 120,000 acres of ARG grown in the Willamette Valley are treated with Axiom DF every year (Hulting, 2013). In fields with a long history of ARG, the most common practice is to apply Axiom DF between the rows when planting new ARG stands in order to suppress volunteer ARG emergence. This practice also enables growers to plant fields earlier, since they do not need to wait for the moisture needed to effectively use preplant broadcast herbicide applications.

Since Axiom DF herbicide is used for weed management in ARG, perennial ryegrass, tall fescue, and wheat production, OSU researchers and the grass seed industry are concerned about additional continuous and widespread use of Axiom DF for row creation. Suspected resistance of ARG to Axiom DF has developed in both field crops and orchards in the Willamette Valley. In order to maintain Axiom as an effective herbicide in field crop production, a need exists to identify alternative herbicides for row spraying purposes. The objective of this study was to evaluate several herbicide products to determine row-spraying utility based on crop safety, row persistence, and seed yield.

Materials and Methods

Two field trials were established during the fall of 2015 to evaluate row spraying at planting in ARG seed fields. The trial at OSU's Schmidt Research Farm was planted to 'Bounty' on September 15, and the Red Bridge Road trial in Linn County was planted to 'Diamond T' on September 18. Experiments were arranged as randomized complete block designs with four replications. Plot size was 5 feet x 30 feet.

At planting, a spray boom was mounted on the front of a plot-sized drill in order to spray while seeding. Both the drill and nozzles (40 03) were at a 10-inch spacing, and a 7.7-inch band of herbicide was sprayed between the drill rows. The ten treatments and application rates are outlined in Table 1. Planting, spraying, and harvest details are outlined in Table 2.

Results and Discussion

The field used at Schmidt Farm did not have a history of ARG; therefore, the objective of the trial was to evaluate crop safety. The on-farm trial at Red Bridge Road was established in a field with a history of ARG seed production; however, very little volunteer ARG was observed in the trial. As a result, we were unable to effectively evaluate the row spraying treatments for control of volunteer ARG; however, plots were evaluated for control of annual bluegrass (*Poa annua*). At Schmidt Farm, most of the herbicide treatments resulted in more than 90% control of *Poa annua* by March of 2016, while average *Poa annua* control at the Red Bridge site was closer to 80% (Table 3). Everest provided the lowest weed control (18%) at Red Bridge, and Eptam provided the lowest control (0%) at Schmidt Farm.

Several of the treatments resulted in more than 20% crop injury, as observed in March 2016 (Table 3).

Table 1. Herbicide treatments used for row spraying at planting in new annual ryegrass seed fields planted in the fall of 2015. (***Note***: The majority of the listed herbicide treatments are not labeled for annual ryegrass seed production.)

Treatment	Active ingredient	Rate
		(lb ai/a)
Control	—	—
Axiom[1]	Flufenacet + metribuzin	0.425
Diuron[1]	Diuron	1.0
Metribuzin	Metribuzin	0.25
Kerb	Pronamide	0.375
Fierce	Pyroxasulfone + flumioxazin	0.095
Alion	Indaziflam	0.013
Matrix	Rimsulfuron	0.047
Everest	Flucarbazone	0.0273
Eptam	EPTC	3.5

[1]Product is labeled for row spraying in ARG seed fields in Oregon.

Table 2. Annual ryegrass planting and row spraying details for trials conducted in Benton County (Schmidt Farm) and Linn County (Red Bridge Road) in 2015–2016.

Trial	Seeding date	Seeding rate	Spray width	Swathing date	Harvest date
		(lb/a)	(in)		
Schmidt Farm	Sep. 15	22	7.7	June 30	July 14
Red Bridge Road	Sep. 18	22	7.7	June 21	July 7

Table 3. *Poa annua* control, crop injury, and clean seed yield results at the two sites harvested in 2016.

	-- *Poa annua* control[1] --		----- Crop injury[1] -----		-------- Seed yield[2] --------	
Treatment	Schmidt	Red Bridge	Schmidt	Red Bridge	Schmidt	Red Bridge
	------------------------- (%) -------------------------				----------- (lb/a) -----------	
Control	0	0	0	0	1,284 a	3,047 a
Axiom	67	93	27	38	1,041 a	2,605 a
Diuron	100	81	1	0	1,217 a	2,682 a
Kerb	100	73	3	0	1,210 a	2,467 a
Metribuzin	99	86	5	0	1,331 a	2,472 a
Fierce	100	94	15	20	1,311 a	2,872 a
Alion	81	86	50	13	1,149 a	2,900 a
Matrix	99	91	3	0	1,404 a	2,539 a
Everest	100	18	3	3	1,367 a	2,882 a
Eptam	0	70	95	3	1,367 a	2,718 a
LSD ($P = 0.05$)					372	495
CV					20	13

[1]Percent control and crop injury evaluated March 17, 2016 at Schmidt Farm and March 23, 2016 at Red Bridge Road.
[2]Means followed by the same letter within the same column are not significantly different at LSD ($P = 0.05$).

Fierce resulted in a similar amount of injury at the two sites (about 20%), while Axiom, Alion, and Eptam behaved differently at the two sites. The Axiom treatment resulted in about 10% more crop injury at the Red Bridge Road site, while Alion and Eptam resulted in drastically more injury at Schmidt Farm. Differences may be explained by planting conditions: the Schmidt Farm trial was planted and sprayed into very dry soil and received nearly an inch of rain the following day; the Red Bridge Road trial was planted into moist and compacted soil. The rain received after planting at Schmidt Farm may have caused the Eptam to move and suppress the ARG stand.

It is important to note there was little-to-no ARG volunteer emerging in either field, and therefore crop injury may not be as severe with added volunteer plants. Also, the spray width of 7.7 inches is aggressive and was used intentionally in order to observe potential injury.

The observed crop injury did not correspond to seed yield differences between treatments. There were no significant differences between any of the treatments at either site for clean seed yield (Table 3). Interestingly, the Eptam treatment at Schmidt Farm had 95% crop injury in March, but yielded just as high as the other treatments. This implies that a new crop of ARG successfully emerged in late spring. Average clean seed yield at Schmidt Farm ranged from 1,041 to 1,404 lb/acre, and from 2,467 to 3,047 lb/acre at Red Bridge Road. Based on the first year of data, row spraying at planting did not increase seed yield over the untreated control, and no row spraying herbicide treatments stood out over others.

Conclusions and Future Work

Axiom application at planting is a common practice for ARG growers that is likely to continue, especially since it allows growers to plant their fields earlier in the fall. Whether the practice is advantageous in terms of input costs per pound of seed is yet to be determined. If growers are to continue the practice of row spraying at planting, it is wise to find other suitable herbicides beyond Axiom so that products can be used in rotation.

Based on the first year of data, there was no difference in yield between any of the treatments, including the untreated control. However, there was very little ARG volunteer pressure in the 2015–2016 trials, and therefore it is not a fair comparison to the reality of Axiom application at planting. Two additional trials with the same treatments were established in the fall of 2016 on fields with heavy ARG volunteer pressure, and these will be evaluated throughout the year and taken to harvest in 2017.

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Acknowledgments

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FALL PREEMERGENCE HERBICIDE APPLICATIONS TO SPRING PLANTINGS OF COOL-SEASON GRASS SEED CROPS IN WESTERN OREGON

D.W. Curtis, K.C. Roerig, A.G. Hulting, and C.A. Mallory-Smith

Introduction

Oregon's grass seed production is dependent on the ability to produce seed free of weed contaminants. Annual bluegrass (*Poa annua*) and roughstalk bluegrass (*Poa trivialis*) represent two major weed seed contamination threats to western Oregon grass seed production. The climate in our growing region allows annual bluegrass to germinate in the fall as rainfall returns to the area and soil temperatures decrease. Germination slows as soil temperatures cool in early winter and then increases as soils warm in the early spring (McElroy et al., 2004). Germination rates slow as soil temperatures rise in late spring. Roughstalk bluegrass germination occurs slightly earlier in the fall if soil moisture is available and continues later in the spring, as it can tolerate warmer soil temperatures.

Two basic planting strategies are utilized to minimize the potential buildup of these two weed species: (1) fall planting with a carbon band protecting the seed row from fall-applied preemergence herbicides, or (2) planting the crop in the spring when warmer soil conditions do not favor weed seed germination. Both planting options are expensive. Fall plantings require the addition of activated carbon slurry plus the application of preemergence herbicides. Alternatively, spring plantings typically need to go through a cold period for vernalization and, thus, need an extra growing season in order to obtain the first seed harvest.

For the production of tall fescue and fine fescue, primarily chewings and creeping red, the industry has found that the spring planting technique is the most cost-effective method for establishment of new stands. The problem growers face, however, is that potential herbicide registrations for preemergence use in spring-planted stands state that they can be applied only following the first harvest.

Materials and Methods

Five studies were conducted with spring-planted grass seed crops from 2010–2016 at Oregon State University's Hyslop Research Farm in Corvallis. The five studies were all planted in the spring, either April or May, and were allowed to go dormant through the low rainfall months of July, August, and September. Studies were arranged in randomized complete block designs with plot size of 8 feet by 35 feet and four replications. Rows of diuron-resistant annual bluegrass (Curtis et al., 2011) and roughstalk bluegrass obtained from screenings provided by local growers were shallowly drilled in the front portions of plots for efficacy evaluations. Applications were made with a unicycle-type small plot sprayer delivering 20 gpa. Study plots were swathed and combined with a modified John Deere plot swather and a Hege 180 combine. Seed was cleaned with a Clipper Cleaner, and yields were quantified. Data were analyzed using ANOVA and means separated by LSD.

Results and Discussion

In 2010–2011, four rates of pyroxasulfone/flumioxazin and a single rate of flufenacet/metribuzin were compared to an untreated check treatment (Table 1). Yields were not affected by herbicide treatments in comparison to the untreated control. All herbicide treatments controlled annual bluegrass at 90% or greater.

A 2012–2013 study compared several herbicide treatments, including flufenacet/metribuzin + diuron, indaziflam, pyroxasulfone, pyroxasulfone/flumioxazin, terbacil + diuron, and metribuzin, with an untreated check treatment for control of roughstalk bluegrass and diuron-resistant annual bluegrass (Table 2). The flufenacet/metribuzin, indaziflam, and pyroxasulfone/flumioxazin controlled roughstalk bluegrass 93% and greater, and these herbicides and pyroxasulfone controlled annual bluegrass 82% or greater with no reductions in yield. No control of the weeds occurred with the terbacil + metribuzin treatment or with metribuzin alone, although no yield reduction occurred.

In 2015, four herbicide treatments were applied to a spring planting of tall fescue at three timings in the fall (Table 3). Flufenacet/metribuzin, pyroxasulfone/flumioxazin, EPTC, and indaziflam were applied 9 days prior to the first major rain event (0.23 inch), 1 day prior to the rain event, and 29 days following the rain event. These treatments were compared to an untreated check. Both roughstalk bluegrass and diuron-resistant annual bluegrass were seeded into the tall fescue plots prior to any herbicide application. With the exception of EPTC, the herbicide treatments provided 93% or better control of the introduced weeds. None of the treatments, including EPTC, reduced yields in comparison to the untreated control (Table 3).

Two studies investigated fall applications of herbicide treatments to spring plantings of creeping red fescue and chewings fescue (Tables 4 and 5). Treatments in these two studies included flufenacet/metribuzin, indaziflam, pyroxasulfone/flumioxazin, dimethenamid-P, A20540B, and s-metolachlor, compared with an untreated check. In the creeping red fescue study, flufenacet/metribuzin, indaziflam, and pyroxasulfone/flumioxazin controlled both weed species at 94% or greater, and no treatments reduced yields. In the chewings fescue study, flufenacet/metribuzin, indaziflam, pyroxasulfone/flumioxazin, and dimethenamid-P controlled roughstalk bluegrass and diuron-resistant annual bluegrass 90% or greater. All treatments, with the exception of indaziflam, reduced yield in comparison to the untreated check. Yield reductions might be mitigated with rate reductions. In all cases, diuron-resistant annual bluegrass was controlled at levels 90% or greater with flufenacet/metribuzin, pyroxasulfone/flumioxazin, and indaziflam. These herbicides also provided at least 93% control of roughstalk bluegrass in four out of five studies. In general, fall applications of flufenacet/metribuzin, pyroxasulfone/flumioxazin, and indaziflam to spring-planted grass seed crops were effective and safe.

Table 1. Control of diuron-resistant annual bluegrass in spring-planted tall fescue, Corvallis, OR, 2010–2011.[1]

Treatment[2]	Rate	Annual bluegrass[3]	Crop injury[3]	Clean seed yield
	(lb ai/a)	(% control)	(%)	(lb/a)
Untreated	0	90	0	1,110
Pyroxasulfone/flumioxazin	0.1	100	5	1,292
Pyroxasulfone/flumioxazin	0.14	100	18	1,227
Pyroxasulfone/flumioxazin	0.19	100	25	1,364
Pyroxasulfone/flumioxazin	0.29	100	45	1,181
Flufenacet/metribuzin	0.43	100	8	1,419
LSD $P = 0.05$		0	7	NS
CV		0	5	14

[1]Planted April, 23, 2010
[2]Applied October 8, 2010
[3]Evaluated April 22, 2011

Table 2. Control of roughstalk bluegrass and diuron-resistant annual bluegrass with fall herbicide applications in spring-planted tall fescue, Corvallis, OR 2012–2013[1]

Treatment[2]	Rate	Roughstalk bluegrass[3]	Annual bluegrass[3]	Crop injury[3]	Clean seed yield
	(lb ai/a)	--------- (% control) ---------		(%)	(lb/a)
Untreated	0	0	0	0	743
Flufenacet/metribuzin	0.55	100	100	0	1,132
+ diuron	2.0				
Indaziflam	0.02	93	92	18	1,008
Pyroxasulfone	0.09	82	100	0	877
Pyroxasulfone/flumioxazin	0.14	98	100	0	925
Terbacil	0.4	0	0	0	903
+ diuron	2.0				
Metribuzin	0.38	0	0	0	869
LSD $P = 0.05$		12	2	7	NS
CV		17	2	190	20

[1]Planted May 2, 2012
[2]Applied October 15, 2012
[3]Evaluated May 24, 2013

Table 3. Fall treatment timings for control of roughstalk bluegrass and diuron-resistant annual bluegrass in spring-seeded tall fescue, Corvallis, OR.[1]

Treatment	Rate	Timing (2015)	Roughstalk bluegrass[2]	Annual Bluegrass[2]	Crop injury[2]	Clean seed yield
	(lb ai/a)		------- (% control) -------		(%)	(lb/a)
Untreated	0	Oct. 2	0	0	0	1,246
Flufenacet/metribuzin	0.55	Oct. 2	100	100	1	1,294
Pyroxasulfone/flumioxazin	0.14	Oct. 2	94	100	3	1,360
EPTC	3.0	Oct. 2	8	8	0	1,313
Indaziflam	0.02	Oct. 2	100	99	8	1,229
Flufenacet/metribuzin	0.55	Oct. 9	100	100	3	1,131
Pyroxasulfone/flumioxazin	0.14	Oct. 9	93	100	3	1,208
EPTC	3.0	Oct. 9	10	13	0	1,335
Indaziflam	0.02	Oct. 9	100	100	10	1,246
Flufenacet/metribuzin	0.55	Nov. 9	100	100	3	1,334
Pyroxasulfone/flumioxazin	0.14	Nov. 9	97	99	4	1,184
EPTC	3.0	Nov. 9	0	0	0	1,132
Indaziflam	0.02	Nov. 9	98	97	15	1,167
LSD $P = 0.05$			8	8	4	NS
CV			8	8	82	13

[1]Planted April 8, 2015
[2]Evaluated April 21, 2016

Table 4. Fall treatments for control of roughstalk bluegrass and diuron-resistant annual bluegrass in spring-planted creeping red fescue, Corvallis, OR, 2015–2016.[1]

Treatment[2]	Rate	Roughstalk bluegrass[3]	Annual bluegrass[3]	Clean seed yield
	(lb ai/a)	---------------- (% control) -----------------		(lb/a)
Untreated	0	0	0	1,065
Flufenacet/metribuzin	0.43	96	99	978
Indaziflam	0.03	97	96	1,095
Pyroxasulfone/flumioxazin	0.14	94	97	1,135
Dimethenamid-P	0.98	86	88	1,054
A20540B[4]	0.82	55	56	1,129
s-metolachlor	0.95	51	53	1,130
LSD $P = 0.05$		14	17	NS
CV		14	16	12

[1]Planted April 10, 2015
[2]Applied November 10, 2015
[3]Evaluated April 21, 2016
[4]A20540B = bicyclopyrone/mesotrione/s-metolachlor

Table 5. Fall treatments for control of roughstalk bluegrass and diuron-resistant annual bluegrass in spring-planted chewings fescue, Corvallis, OR 2015–2016.[1]

Treatment[2]	Rate	Roughstalk bluegrass[3]	Annual bluegrass[3]	Crop injury[3]	Clean seed yield
	(lb ai/a)	--------- (% control) ---------		(%)	(lb/a)
Untreated	0	0	0	0	1,321
Flufenacet/metribuzin	0.43	98	100	14	981
Indaziflam	0.03	99	100	4	1,183
Pyroxasulfone/flumioxazin	0.14	95	97	1	1,080
Dimethenamid-P	0.98	90	94	3	1,000
A20540B[4]	0.82	60	60	0	1,117
s-metolachlor	0.95	61	70	0	1,067
LSD $P = 0.05$		7	9	7	162
CV		7	8	138	10

[1]Planted April 10, 2015
[2]Applied November 11, 2015
[3]Evaluated April 21, 2016
[4]A20540B = bicyclopyrone/mesotrione/s-metolachlor

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Acknowledgments

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CROP SAFETY OF FIERCE (FLUMIOXAZIN + PYROXASULFONE) HERBICIDE IN ESTABLISHED KENTUCKY BLUEGRASS, GRANDE RONDE VALLEY OF NORTHEASTERN OREGON

D.L. Walenta

Introduction

A study was conducted in the Grande Ronde Valley of northeastern Oregon to evaluate crop safety and efficacy with Fierce herbicide (flumioxazin + pyroxasulfone) in established Kentucky bluegrass. Fierce is not registered for use in grasses grown for seed and previously had not been evaluated for potential fit in Kentucky bluegrass seed production.

Materials and Methods

The experiment was located in an established commercial field of 'Endurance' Kentucky bluegrass (KBG) in the Grande Ronde Valley of northeastern Oregon. The field was seeded during the spring of 2014, and a second seed crop was harvested in 2016. Early postemergent (EPOST) herbicide applications were made on October 12, 2015. Late postemergent (LPOST) herbicide applications were made on November 12, 2015. Conditions at the time of application are summarized in Table 1. All treatments were applied with a hand-held CO_2 sprayer delivering 22 gpa at 30 psi. To minimize drift potential, TeeJet air induction extended range (AIXR) 11002 nozzle tips were used for all applications. Plots were 8 feet x 25 feet and arranged in a randomized complete block design with four replications. Soil at the site consisted of an Imbler fine sandy loam (72% sand, 22.8% silt, 5.2% clay, 2.73% OM, 5.1 pH, and CEC of 16.0 meq/100g). Seed yield was not quantified in this study due to crop destruct requirements; however, the number of KBG panicles per 0.25 m^2 was determined to estimate potential seed yield.

Results and Discussion

Weed control evaluations were not possible due to lack of weed pressure. However, all EPOST treatments resulted in excellent volunteer Kentucky bluegrass control 30 days after treatment (DAT) (Table 2).

Crop injury evaluations were made 30 days after the EPOST application date, 20 weeks after the LPOST application date, and at crop maturity (Table 2; evaluation at crop maturity shown as KBG heads/0.25 m^2). Fierce applied pre- or early post-emergence at 3 oz/acre as a stand-alone treatment or in tank-mix combinations with either oxyfluorfen (Goal 2XL) or diuron resulted in acceptable crop injury (3–5%) 30 days after treatment. At crop maturity, however, these same treatments resulted in fewer panicles/0.25 m^2 (16–27% less), compared to the untreated check, but were not statistically different. Sequential LPOST applications of dimethenamid-P (Outlook) and Outlook + metribuzin after Fierce was applied EPOST resulted in unacceptable crop injury (16–17%) 20 weeks after treatment. Panicle number was reduced by 58% (compared to the untreated check) at crop maturity.

Flufenacet + metribuzin (Axiom DF) and metribuzin were also included in this study to evaluate the potential

Table 1. Conditions at time of herbicide application.

	Application timing	
	Oct. 12, 2015 (early postemergent)	Nov. 12, 2015 (late postemergent)
KBG growth stage	4–6 inches regrowth	> 6 inches regrowth
Volunteer KBG growth stage	1 inch, one leaf	1 inch, one to two leaves, 0 tillers
Air temperature (°F)	54	42
Relative humidity (%)	67	71
Cloud cover (%)	Clear	100
Wind velocity (mph)	Calm	7 mph from SW
Soil temp at surface (°F)	55	41
Soil temp at 1-inch depth (°F)	52	42
Soil temp at 2-inch depth (°F)	54	42
Soil temp at 4-inch depth (°F)	58	42

for grass weed control and crop injury in eastern Oregon Kentucky bluegrass seed production. Metribuzin was used as a tank-mix partner to increase the spectrum of weed control at LPOST application timing. All Axiom DF treatments were applied EPOST and resulted in 10–15% visible crop injury 30 days after treatment and 64–80% reduction in panicles at crop maturity. The most severe crop injury (65% visible injury and 85% reduction in panicles) was observed when Axiom DF was applied EPOST at 8 oz/acre, followed by LPOST application of Fierce at 3 oz/acre. This result suggests that late sequential applications of Fierce may increase crop injury.

Note: Flumioxazin + pyroxasulfone (Fierce), flufenacet + metribuzin (Axiom DF), and metribuzin are not registered for use in eastern Oregon Kentucky bluegrass seed production and were evaluated on an experimental basis only. Mention of products used in this trial should not be considered a recommendation for commercial use. Additional research needs to be conducted to determine whether improved grass and broadleaf weed control can be achieved and whether crop injury will prevent the use of these products in Kentucky bluegrass seed production.

Acknowledgments

The author thanks TRICO Farms and Pacific Ag Resources for their collaborative support of this study.

Table 2. Efficacy and crop safety of Fierce (flumioxazin + pyroxasulfone) in established Kentucky bluegrass in the Grande Ronde Valley of northeastern Oregon, 2016.

Treatment[2,3]	Application rate	Application timing	Crop Injury[1] Nov. 12, 2015	Crop Injury[1] April 9, 2016	Volunteer KBG control[1] Nov. 12, 2015	KBG heads[1] June 25, 2016
	(per acre)		(%)	(%)	(%)	(number/0.25 m²)
Check	—	—	0 b	0 d	0 b	669 a
Fierce	3 oz	EPOST	3 a	9 bcd	94 a	558 ab
Fierce +	3 oz	EPOST	4 a	7 bcd	95 a	537 ab
Goal 2XL	2 oz					
Fierce /fb/	3 oz	EPOST	3 ab	6 cd	92 a	489 b
Diuron 4L	20 oz	LPOST				
Fierce /fb/	3 oz	EPOST	4 a	16 b	94 a	281 c
Outlook	21 oz	LPOST				
Fierce +	3 oz	EPOST	5 a	17 b	92 a	277 c
Goal 2XL /fb/	2 oz	LPOST				
Outlook +	21 oz					
Metribuzin DF	4 oz					
Axiom DF	8 oz	EPOST	0 b	10 bc	93 a	243 cd
Axiom DF	10 oz	EPOST	0 b	15 bc	92 a	135 cd
Axiom DF /fb/	8 oz	EPOST	<1 b	11 bc	91 a	172 cd
Diuron 4L	20 oz	LPOST				
Axiom DF /fb/	8 oz	EPOST	<1 b	65 a	95 a	97 d
Fierce	3 oz	LPOST				
LSD ($P = 0.05$)			3	10	6	177

[1]Means with the same letter in the same column are not statistically different.

[2]Fierce = flumioxazin + pyroxasulfone; Goal = oxyfluorfen; Outlook = dimethenamid-P; Axiom DF = flufenacet + metribuzin

[3]fb = followed by

EVALUATION OF CROP INJURY FROM SEQUENTIAL HERBICIDE APPLICATIONS FOR CHEATGRASS (*BROMUS TECTORUM*) CONTROL IN ESTABLISHED KENTUCKY BLUEGRASS, GRANDE RONDE VALLEY OF NORTHEASTERN OREGON

D.L. Walenta, A.G. Hulting, B. Merrigan, and D.W. Curtis

Introduction

"Cheatgrass" or downy brome (*Bromus tectorum*, BROTE) is a persistent annual grass weed in northeastern Oregon grass seed production systems. Current integrated pest management practices for cheatgrass include herbicide application, bale plus propane flaming postharvest residue, and hand-rogueing. Herbicide application at a single timing (preemergent or postemergent) typically does not provide adequate cheatgrass control. A study was conducted in established Kentucky bluegrass (KBG) to evaluate cheatgrass control and crop injury potential from sequential applications of selected preemergent and postemergent herbicides currently registered for use in grass seed.

Materials and Methods

The experiment was located in an established commercial field of 'Endurance' KBG in the Grande Ronde Valley of northeastern Oregon. The field was seeded in the spring of 2014, and a second seed crop was harvested in 2016. Preemergent herbicide applications (PRE) were applied on September 11, 2015. Postemergent herbicide applications were made on October 13, 2015 (EPOST) and February 25, 2016 (MPOST and LPOST). Conditions at the time of application are summarized in Table 1.

All treatments were applied with a hand-held CO_2 sprayer delivering 22 gpa at 30 psi. In order to minimize drift potential, TeeJet air induction extended range (AIXR) 11002 nozzle tips were used for all applications. Plots were 8 feet by 25 feet and were arranged in a randomized complete block design with four replications. Soil at the site consisted of an Imbler coarse sandy loam (81% sand, 15.8% silt, 3.2% clay, 2.62% OM, 5.5 pH, and CEC of 12.0 meq/100g). Visual evaluations of crop injury were taken in fall 2015 (October 2, October 13) and spring 2016 (April 19). KBG crop injury was based on a 0 to 100% scale, where 10% sets the limit of acceptable crop injury for most growers. Seed yield was not determined in this study.

Results and Discussion

Cheatgrass populations were very low throughout the growing season. Therefore, it was not possible to determine effectiveness of sequential herbicide applications for weed control.

Symptoms of injury appeared as stunted plant growth and burned-back foliage. Observations of crop injury were made for treatments including Axiom (flufenacet + metribuzin), Outlook (dimethenamid-P), and Beacon (primsulfuron). Results are summarized in Table 2. Most notable was the significant injury caused by Axiom applied in mid-October (EPOST) and late February (MPOST), but injury was expected given the use restrictions for east of the Cascade Mountains (e.g., loamy sand soil type; do not apply after late November). Injury from preemergent-applied Axiom was significant

Table 1. Conditions at time of herbicide application.

	-------------------- Application timing --------------------		
	Sep. 11, 2015 (preemergent)	Oct. 13, 2015 (early postemergent)	Feb. 25, 2016 (mid- and late postemergent)
KBG growth stage	4 inches regrowth	4–7 inch height	Initiating growth
BROTE growth stage	None observed	None observed	None observed
Air temperature (°F)	90	61	59
Relative humidity (%)	31	54	43
Cloud cover (%)	Clear and sunny	Clear and sunny	Clear and sunny
Wind velocity (mph)	Calm	Calm	0–3
Soil temp at surface (°F)	92	62	70
Soil temp at 1-inch depth (°F)	84	59	60
Soil temp at 2-inch depth (°F)	82	57	56
Soil temp at 4-inch depth (°F)	78	53	45

Table 2. Cheatgrass (BROTE) control in established Kentucky bluegrass in the Grande Ronde Valley of northeastern Oregon, 2016.

			Crop injury[1]			BROTE
Treatment[2]	Applicate rate	Application timing	Oct. 2, 2015	Oct. 13, 2015	April 19, 2016	April 19, 2016
	(per acre)		(%)			(number of plants/plot)
Check	—	—	0 d	0 c	0 e	8
Prowl H2O	5 pt	PRE	0 d	0 c	0 e	1
Axiom	10 oz	PRE	13 a	29 a	8 d	<1
Outlook	21 oz	PRE	8 c	11 b	1 e	<1
Prowl H20 /	5 pt	PRE	0 d	0 c	0 e	2
Goal 2XL +	8 oz	EPOST				
metribuzin	4 oz					
Axiom	10 oz	EPOST	0 d	0 c	16 b	3
Prowl H2O /	5 pt	PRE	0 d	0 c	0 e	2
Goal 2XL +	8 oz	MPOST				
Sinbar	0.5 oz[3]					
Prowl H2O /	5 pt	PRE	0 d	0 c	0 e	3
Goal 2XL +	16 oz	MPOST				
metribuzin	4 oz					
Prowl H2O /	5 pt	PRE	0 d	0 c	10 cd	3
Beacon +	0.38 oz	MPOST				
Sinbar	0.5 oz[3]					
Prowl H2O /	5 pt	PRE	0 d	0 c	0 e	1
Callisto +	6 oz	MPOST				
Sinbar	0.5 oz					
Outlook /	21 oz	PRE	8 c	9 b	65 a	1
Axiom	10 oz	MPOST				
Outlook /	21 oz	PRE	10 b	8 b	0 e	1
Goal 2XL +	8 oz	MPOST				
Sinbar	0.5 oz[3]					
Prowl H2O /	5 pt	PRE	0 d	0 c	15 bc	3
Beacon /	0.38 oz	EPOST				
Beacon +	0.38 oz	MPOST				
Sinbar	0.5 oz[3]					
Prowl H2O /	5 pt	PRE	0 d	0 c	8 d	1
Outlook /	21 oz	EPOST				
Beacon	0.38 oz	LPOST[4]				
Goal 2XL +	5 pt	EPOST	0 d	0 c	9 d	1
metribuzin /	4 oz	MPOST				
Beacon +	0.38 oz					
Sinbar	0.5 oz[3]					
LSD (*P* = 0.05)			1.8	4.0	5.0	NS

[1]Means with the same letter are not statistically different.

[2]Axiom = flufenacet + metribuzin; Prowl H2O = pendimethalin; Goal 2XL = oxyfluorfen; Callisto = mesotrione; Sinbar = terbacil; Outlook = dimethenamid-P; Beacon = primsulfuron

[3]Sinbar rates should have been applied at 0.5 lb product/acre.

[4]LPOST treatment was applied at time of MPOST (February 25, 2016).

in fall 2015; however, symptoms diminished to visually acceptable levels by April 19, 2016. Visual observations suggested a reduction in the number of seed heads, but neither head counts nor yield data were collected in this study.

PRE and EPOST applications of Outlook demonstrated greater crop safety than Axiom, but still caused 8 to 10% crop injury in early fall; however, the injury symptoms dissipated by mid-April. Unacceptable crop injury (15%) was observed on April 19 from sequential applications of Prowl H20 at 5 pt/a applied PRE, followed by a full rate of Beacon split-applied between mid-October (0.38 oz/acre EPOST) and late February (0.38 oz/acre LPOST). All other Beacon treatments (0.38 oz/acre) were applied at MPOST and resulted in 8 to 10% crop injury, whether tank-mixed with Sinbar or not. Please note that all Sinbar rates should have been applied at 0.5 lb product/acre.

Note: Flufenacet + metribuzin (Axiom) and metribuzin active ingredients are not registered for use in eastern Oregon Kentucky bluegrass seed production and are being evaluated on an experimental basis only. Mention of products used in this trial should not be considered a recommendation for commercial use.

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CROP SAFETY OF ALION (INDAZIFLAM) HERBICIDE IN ESTABLISHED KENTUCKY BLUEGRASS, GRANDE RONDE VALLEY OF NORTHEASTERN OREGON

D.L. Walenta

Introduction

A study was conducted in the Grande Ronde Valley of northeastern Oregon to evaluate Alion (indaziflam), a group 29 mode of action herbicide, for crop safety and preemergent grass weed control efficacy in established Kentucky bluegrass. Alion is not registered for use in grasses grown for seed and previously had not been evaluated for potential fit in Kentucky bluegrass seed production.

Materials and Methods

The experiment was located in an established commercial field of 'Endurance' Kentucky bluegrass (KBG) in the Grande Ronde Valley of northeastern Oregon. The field was seeded during the spring of 2014, and a second seed crop was harvested in 2016. Alion was applied at 1.0, 1.5, and 2.0 oz/acre at each of three application timings. Preemergent herbicide treatments (PRE) were applied on September 15, 2015. Early postemergent herbicide treatments (EPOST) were applied on October 12, 2015. Late postemergent herbicide treatments (LPOST) were applied February 25, 2016. Pendimethalin (Prowl H2O) was applied at 5 pt/acre PRE in the fall ahead of the winter LPOST applications. Oxyfluorfen (Goal 2XL) was tank-mixed with EPOST Alion treatments to provide burndown activity at time of application.

Conditions at the time of application are summarized in Table 1. All treatments were applied with a hand-held CO_2 sprayer delivering 22 gpa at 30 psi. To minimize drift potential, TeeJet air induction extended range (AIXR) 11002 nozzle tips were used for all applications. Plots were 8 feet x 25 feet and were arranged in a randomized complete block design with four replications. The soil type at the site was an Imbler fine sandy loam (72% sand, 22.8% silt, 5.2% clay, 2.73% OM, 5.1 pH, and CEC of 16.0 meq/100g). Seed yield was not quantified in this study due to crop destruct requirements.

Results and Discussion

Weed control evaluations were not possible due to the lack of weed pressure. KBG did not exhibit any injury 30 days after preemergent treatments were applied (Table 2). In mid-November, slight crop injury (1–2%) was observed in PRE (Alion at 1.0 and 2.0 oz/acre) and EPOST (Alion tank-mixed with Goal 2XL) treatments. Crop injury observations made in early spring indicated slightly more noticeable injury (1–5%) in all treatments, but injury was still well below a commercially acceptable level. Overall, Kentucky bluegrass injury observed in this study indicates that Alion applied PRE, EPOST, and LPOST can cause noticeable but acceptable levels of injury. Visual observations indicated crop injury symptoms dissipated from mid-April until the study was terminated.

Volunteer KBG control in mid-November was good to excellent at the 1.5 to 2.0 oz/acre rates of Alion applied

Table 1. Conditions at time of herbicide applications.

	Application timing		
	September 15, 2015 (preemergent)	October 12, 2015 (early postemergent)	February 25, 2016 (late postemergent)
KBG growth stage	3–5 inches regrowth	4–6 inches regrowth	4–6 inches regrowth
Volunteer KBG growth stage	1 inch, one leaf	1 inch, one leaf	1 inch, one to two leaves, 0 tillers
Air temperature (°F)	60	54	54
Relative humidity (%)	45	67	56
Cloud cover (%)	100	Clear	Sunny
Wind velocity (mph)	Calm	Calm	4–7 mph from S-SW
Soil temp at surface (°F)	61	55	61
Soil temp at 1-inch depth (°F)	60	52	52
Soil temp at 2-inch depth (°F)	60	54	43
Soil temp at 4-inch depth (°F)	60	58	38

PRE and EPOST. The low 1.0 oz/acre Alion rate was not as effective at later application timings.

Note: Indaziflam is not registered for use in grasses grown for seed and is being evaluated on an experimental basis only. Mention of products used in this trial should not be considered a recommendation for commercial use. More research is needed to determine how indaziflam may fit into the Kentucky bluegrass seed production system.

Acknowledgments
The author thanks TRICO Farms and Pacific Ag Resources for their collaborative support of this study.

Table 2. Efficacy and crop safety of Alion (indaziflam) herbicide in established Kentucky bluegrass, Grande Ronde Valley of northeastern Oregon, 2016.

	Application rate	Application timing	------------ Crop injury ------------		Volunteer KBG control[1]	Crop injury
Treatment[2]	(per acre)		Oct. 14, 2015	------ Nov. 12, 2015 ------		April 9, 2016
			------------------- % -------------------			
Check	—	—	0	0	0 b	0
Alion	1 oz	PRE	0	2	86 a	2
Alion	1.5 oz	PRE	0	0	86 a	3
Alion	2 oz	PRE	0	2	92 a	5
Alion + Goal 2XL	1 oz 3 oz	EPOST	0	1	67 a	2
Alion + Goal 2XL	1.5 oz 3 oz	EPOST	0	2	75 a	3
Alion + Goal 2XL	2 oz 3 oz	EPOST	0	1	77 a	3
Alion	1 oz	LPOST[3]	0	1	66 a	2
Alion	1.5 oz	LPOST[3]	0	0	74 a	1
Alion	2 oz	LPOST[3]	0	1	75 a	1
LSD (*P* = 0.05)			NS	NS	34	NS

[1]Means with the same letter are not statistically different.
[2]Alion = indaziflam; Goal = oxyfluorfen
[3]Prowl H2O applied PRE to plots on September 15, 2015.

MONITORING ERGOT INFECTION POTENTIAL IN COMMERCIAL CULTIVARS OF KENTUCKY BLUEGRASS, GRANDE RONDE VALLEY OF NORTHEASTERN OREGON

D.L. Walenta, N. Kaur, J.K.S. Dung, S.C. Alderman, and K.E. Frost

Introduction

A study was conducted in the Grande Ronde Valley of northeastern Oregon to evaluate ergot infection potential, crop phenology, and seed yield in eight commercial cultivars of Kentucky bluegrass (KBG). Ergot, caused by the fungal pathogen *Claviceps purpurea*, is a floral disease of cool-season grass seed crops in Oregon and Washington. The pathogen infects unfertilized flowers of host grasses and forms sclerotia instead of seed, which results in yield loss and reduced seed quality. Sclerotia overwinter and germinate in the spring to produce fruiting bodies called capitula, which in turn release millions of airborne ascospores.

The release of ascospores typically coincides with grass flowering (anthesis), which is the only period of host susceptibility. The objective of this study was to evaluate the potential of KBG cultivars to escape infection by ergot based on the flowering period of each cultivar in relation to peak ascospore production.

Materials and Methods

The trial (KBG-3) was direct seeded on April 2, 2015 in a commercial field of winter wheat with a 10-foot double disc plot drill with eight openers set on a 15-inch row spacing. The trial site had been treated with glyphosate 30 days before seeding to control the winter wheat crop and stabilize the soil to prevent wind erosion as the new stand of KBG established. The seeding rate for each cultivar was 5 lb/acre. KBG cultivars were selected based on importance to the local seed industry and potential to cover a range of flowering dates. Plots were 10 feet x 32 feet and were arranged in a randomized complete block design with four replications. Soil type at the site was an Imbler fine sandy loam (77% sand, 19.8% silt, 3.2% clay, 2.0% OM, 5.9 pH, and CEC of 11.4 meq/100g).

Crop phenology was assessed weekly from mid-April to late June to determine timing and duration of flowering for each KBG cultivar. The Feekes scale was used to stage crop development. Initial appearance of stigmas and/or anthers is considered to be the beginning of flowering (Feekes 10.51). Flowering was considered to be complete when at least 90% of the plot reached Feekes 11.1 (milk stage). Since phenology observations were made on a weekly basis, estimates were collected at flowering initiation and completion to determine the percentage of panicles at Feekes 10.51 and 11.1 development stages.

A Burkhard 7-day recording volumetric spore trap was used to monitor and quantify ascospore release on a continual basis from April 20 to June 21, 2016. The trap was located in the center of the KBG-3 trial site, with the air intake orifice located approximately 2 feet above the soil surface. Spore trap tapes were collected weekly, and the number of *C. purpurea* ascospores was determined microscopically on an hourly and daily basis. A second monitoring site was also located in a commercial field of 'Baron' Kentucky bluegrass (KBG-4) situated 0.25 mile northeast of Imbler, OR.

Disease incidence was monitored from May 31 to June 24. Final observations were collected on June 24, 2016 to determine disease incidence and severity by collecting 40 panicles randomly from each plot at the KBG-3 site. Incidence was calculated based on the number of panicles containing ergot sclerotia. Severity was calculated based on the number of sclerotia present in each infected panicle. Plots were swathed on June 29, 2016 and combine harvested on July 24, 2016. The KBG-4 site was utilized to monitor ergot ascospore activity and crop phenology only.

Seed yield was determined by processing samples at the OSU-Hermiston Agricultural Research and Extension Center in Hermiston, OR. The 4- to 6-kg seed samples from each harvested plot were weighed to determine total weight of uncleaned seed. Next, 1,000-gram (approximate weight) subsamples were collected for conditioning to determine clean seed yield/acre. Each subsample was debearded for 4½ minutes and then cleaned with a Clipper 3-screen cleaner set up with 7-round top, 7-round middle, and 6 x 34 mesh bottom screens. Clean seed yield/plot was calculated based on cleanout percentage for each subsample and is expressed as a percentage of the industry standard 'Abbey' KBG.

Results and Discussion

Overall, ergot ascospore production was very low at both monitoring sites during the 2016 growing season (Figure 1). Only 36 ascospores were collected during the entire season at the KBG-3 variety trial site, from May 2 to June 1 (31 days). Even fewer ascospores (12) were collected at the 'Baron' commercial field (KBG-4) monitoring site during a shorter (15-day) period from May 6 to May 20.

Flowering period initiation and completion dates were determined for each cultivar (Table 1). 'Wildhorse', 'Endurance', 'ThermalBlue', 'Jumpstart', and 'Prosperity' began flowering between May 10 and May 17. 'Baron' and 'Abbey' began flowering between May 17 and May 24. 'Midnight II' began flowering May 17.

Peak ascospore activity at the KBG-3 site occurred between May 5 and May 8 (Figure 1), which was approximately 7–10 days before the early-flowering cultivars 'ThermalBlue', 'Jumpstart', and 'Wildhorse' began flowering (Table 1). After May 8, ascospore activity diminished and was intermittent until June 1, when ascospore activity ended.

The low ascospore density still presented a low risk for ergot infection in mid- to late May, since all cultivars were in various stages of flowering at that time. The risk of infection for 'ThermalBlue' and 'Jumpstart' cultivars was very low, as both had finished flowering by June 7; the end of their flowering period preceded that of all other cultivars by 7 days or more. 'Wildhorse' was at higher infection risk because its flowering stage lasted from mid-May to mid-June.

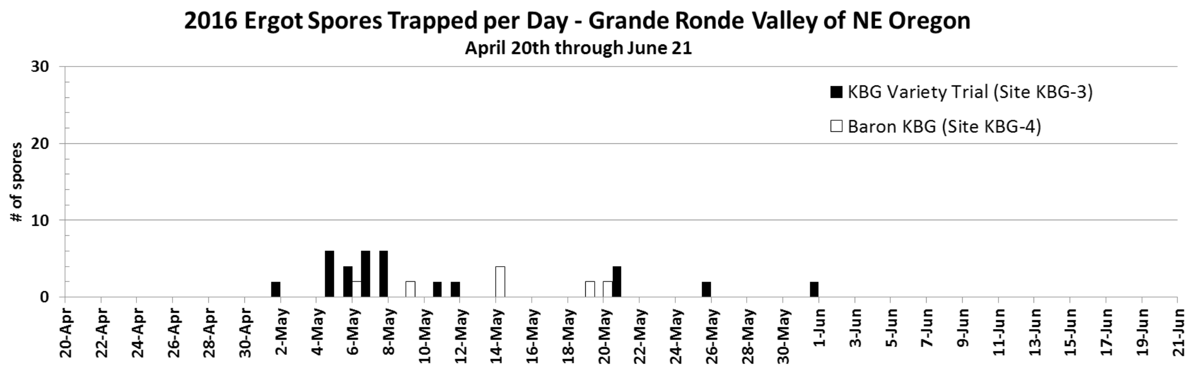

Figure 1. Results from two ergot monitoring sites in the Grande Ronde Valley of northeastern Oregon, 2016.

Table 1. Flowering period, ergot incidence, and seed yield for eight Kentucky bluegrass cultivars, Grande Ronde Valley of northeastern Oregon, 2016.

	---- Flowering period and % of panicles ----			Ergot incidence	---------- Seed yield[1] ----------	
Cultivar	Initiation[2,3]	End[4]	Period			
			(days)		(lb/a)	% Abbey
Baron	May 24 (80)	June 14 (75)	21	0	1,408 a	109 a
Wildhorse	May 17 (60)	June 14 (70)	28	0	1,406 a	109 a
Abbey	May 24 (65)	June 14 (95)	21	0	1,407 a	100 ab
Endurance	May 17 (30)	June 14 (92)	28	0	1,286 a	99 ab
ThermalBlue	May 17 (90)	June 7 (96)	21	0	1,107 ab	93 ab
Jumpstart	May 17 (65)	June 7 (100)	21	0	1,139 ab	88 ab
Prosperity	May 17 (25)	June 14 (50)	28	0	1,123 ab	87 ab
Midnight II	May 17 (1)	June 14 (75)	28	0	871 b	73 b
LSD (*P* = 0.05)					391	28.6

[1]Preliminary yield results
[2]Initiation of flowering period = Feekes 10.51 (flowering)
[3]No flowering was observed in any cultivars on May 10, 2016.
[4]End of flowering period = Feekes 11.1+ (milk stage)

Symptoms of ergot infection (honeydew) were not observed at any time prior to harvest at either the KBG-3 or KBG-4 site. Preharvest evaluations to determine disease incidence levels did not detect any honeydew or sclerotia in KBG panicles collected at the KBG-3 site.

First-year seed yields (Table 1) variedly considerably from 903 to 1,747 lb/acre across all cultivars and replications. 'Baron' and 'Wildhorse' yielded 9% more clean seed than the industry standard 'Abbey', but their yields were not statistically different from those of any other cultivar except for 'Midnight II', which yielded 23% less.

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DEVELOPMENT OF A PREDICTIVE DEGREE-DAY MODEL FOR AIRBORNE ERGOT ASCOSPORES IN PERENNIAL RYEGRASS SEED PRODUCTION SYSTEMS OF EASTERN OREGON

J.K.S. Dung, S.C. Alderman, N. Kaur, D.L. Walenta, K.E. Frost, and P.B. Hamm

Introduction

Ergot is a major disease of perennial ryegrass seed crops in the Columbia Basin of Oregon and other irrigated production regions of the Pacific Northwest. Ergot reduces yield, hinders seed certification efforts, and can be particularly difficult to manage. The fungus that causes ergot, *Claviceps purpurea*, infects the unfertilized flowers of grasses and grains and transforms seed into dormant resting structures (sclerotia) of the fungus, which overwinter and produce primary inoculum (ascospores) the following season.

Since ergot infects only unfertilized flowers, ascospore production by the fungus must coincide with the flowering of susceptible grass hosts for infection to occur. In some years, the timing of spore release and host anthesis does not coincide, resulting in little to no ergot. It is suspected that environmental conditions can contribute to this lack of synchrony between host anthesis and pathogen spore production. We hypothesize that an ergot phenology model can be used to inform growers if or when fungicides may be necessary and improve the timing of fungicide application to enhance ergot control. The objective of this study was to develop and validate a predictive model for ergot spore production in perennial ryegrass seed production systems of eastern Oregon.

Materials and Methods

Burkard 7-day volumetric spore traps (Burkard Scientific Ltd., Uxbridge, Middlesex, UK) were used to trap airborne ascospores of *C. purpurea* in three commercial perennial ryegrass fields and two artificially infested perennial ryegrass plots between 2013 and 2015. All fields and plots were located in Umatilla County, OR, subjected to similar cultural practices, and irrigated using center pivot irrigation as is typical in the region.

A spore trap was placed in field BASIN-A (cv. 'Pavilion') between April 3 and June 19, 2013 and from April 22 to June 27, 2014. In 2013, spores were sampled from field BASIN-B (cv. 'Top Hat II') between April 3 and June 15. Field BASIN-C (cv. 'Pavilion') was sampled from April 2 to June 22, 2015. Spore traps were placed in artificially infested plots at the Hermiston Agricultural Research and Extension Center (HAREC) between April 11 and June 23 in 2014 and from April 4 to June 22 in 2015. Spore traps were situated in the grass seed crops approximately 500 feet from the field borders, and the air intake orifices were approximately 1.5 feet above ground level. Spore trap tapes were collected weekly, processed, and analyzed as described by Alderman (1993). The number of ascospores trapped per hour was counted under a microscope at 300X magnification to determine ascospore counts for each 24-hour period (12:00 a.m. to 11:59 p.m.).

Daily minimum and maximum air temperature data were compiled from the HRMO weather station in the AgriMet Northwest Cooperative Agricultural Weather Network, which is located at the HAREC. Degree-days were calculated beginning on January 1 of each year. A base temperature of 50°F and an upper threshold temperature of 77°F were used for degree-day calculations based on previous studies (Uppala et al., 2012) and weather data collected in this study.

The degree-day model was validated using spore trap data that were not used for model development. The spore trap data used for model validation were collected as described above in five different 125-acre commercial perennial ryegrass seed fields (2008, 2009, 2010, 2012, and 2016) and two artificially infested 1-acre perennial ryegrass seed plots located at HAREC (2010 and 2016). All five commercial fields were planted and managed by the same grower as the other commercial fields used in this study.

Results and Discussion

Overall, a degree-day period between 414 and 727 accounted for the occurrence of 93% of the total ascospores trapped between 2008 and 2016 (Table 1). Among the individual years, the degree-day period accounted for 96%, 76%, and 94% of the total ascospores trapped in 2013, 2014, and 2015, respectively. When validated against historical data, the degree-day model accounted for 82% of ascospores trapped in 2008, 84% of ascospores trapped in 2009, 90% of the total ascospores trapped in 2010, and 87% of total ascospores trapped in 2012. The degree-day model was tested using spore trap data in 2016 and accounted for 85% of the total ascospores trapped

Table 1. Number of *Claviceps purpurea* ascospores trapped when accumulated degree-days were between 414 and 727 compared to the total number of ascospores trapped during the cool-season grass seed production season at 11 study sites, Umatilla County, OR, 2008–2016.[1]

					----------- Ascospores trapped -----------		
Year	Start date	End date	Days	Field	Degree-days 414 to 727	Entire season	% total
2008	May 25	June 17	23	BASIN-08	6,472	7,855	82
2009	May 24	June 9	16	BASIN-09	12,335	14,673	84
2010	May 18	June 17	30	BASIN-10	1,650	2,270	73
				HAREC-10	14,046	15,196	92
2012	May 19	June 14	26	BASIN-A	5,307	6,124	87
2013	May 11	June 7	27	BASIN-A	54,114	56,144	96
				BASIN-B	109,726	114,525	96
2014	May 12	June 2	21	BASIN-A	12,402	16,236	76
				HAREC-14	1,580	2,260	70
2015	May 4	May 26	22	BASIN-C	37,070	38,917	95
				HAREC-15	666	1,083	61
2016	May 1	May 24	23	BASIN-16	1,538	1,820	85
				HAREC-16	192	208	92
Average	May 14	June 6	23.5	—	257,098	277,311	93

[1]Air degree-days were calculated using lower and upper thresholds of 50 and 77°F, respectively. Degree-day accumulations began on January 1.

in 2016, indicating that this degree-day model is a useful predictor for ascospore production periods. Additionally, the degree-day model was tested using spore trap data collected from Kentucky bluegrass fields in central Oregon and accounted for 91 and 84% of ascospores trapped in 2015 and 2016, suggesting that this model may be useful for other irrigated grass seed production regions.

The degree-day period identified in this study started as early as May 1 (in 2016) or as late as May 25 (in 2008) and ended as early as May 24 (in 2016) or as late as June 17 (in 2008 and 2010). The length of this degree-day period ranged between 16 and 30 days, averaging 23.5 days between 2008 and 2016.

Fungicides labeled for ergot in grass seed crops have application intervals ranging from 10 to 21 days, suggesting that growers could use this model for informed timing of two or three fungicide sprays during anthesis, thus protecting their crops against the majority of ascospores produced during the season. However, it is important to note that a small proportion of ascospores can be present before the beginning of the degree-day period identified in this study, so growers may need to make their first fungicide application prior to the degree-day period to ensure flowers are protected before inoculum production begins.

To our knowledge, this is the first predictive degree-day model developed for *C. purpurea* ascospore production. The ability to predict when *C. purpurea* ascospores are most likely to be present will help inform growers if or when fungicide applications would be required during anthesis of grass seed crops. It is anticipated that this model will become an important component of an integrated disease management strategy that incorporates cultural practices, host resistance and/or disease escape, field scouting (Dung et al., 2013), spore trapping (Dung et al., 2016), chemical control (Dung et al., 2013), and grower outreach (Walenta et al., 2016) to improve ergot management in perennial ryegrass seed crops.

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PROSPECTS FOR ERGOT DISEASE MANAGEMENT WITH BIOCONTROL PRODUCTS

N. Kaur, J.K.S. Dung, D.L. Walenta, and K.E. Frost

Introduction

Ergot, caused by the fungus *Claviceps purpurea,* is a floral disease of grasses and a persistent problem in grass seed production systems in eastern Oregon and Washington. Ergot control is difficult due to the vast number of sclerotia that can remain in the soil after seed harvest (Dung et al., 2016). Use of biocontrol agents may reduce or delay sclerotia germination and reduce ergot infection by decreasing the abundance of sclerotia. Biocontrol research over the past 100 years has indicated that antagonistic microorganisms can act to inhibit disease occurrence and/or progression (McSpadden et al., 2002). The discovery of an effective biocontrol agent would provide another management option for integration into existing ergot management approaches in Pacific Northwest grass seed production systems.

Mycoparasitic fungi causing degradation of *C. purpurea* sclerotia have been previously reported (Ondřej et al., 2010). However, information is limited about the occurrence of microorganisms naturally associated with *C. purpurea* sclerotia in grass seed production regions of Oregon and Washington and their parasitic potential. This research focused on the discovery and evaluation of potential biocontrol options that can be readily incorporated into an integrated ergot disease management plan. Our research objectives were to: (1) isolate and screen naturally occurring microorganisms with potential to parasitize ergot sclerotia, and (2) evaluate commercial products for their ability to delay or reduce ergot sclerotia germination.

Materials and Methods

Isolation and screening of fungi and bacteria on *C. purpurea* sclerotia

A baiting technique was used to attract and isolate naturally occurring microorganisms that may be able to parasitize *C. purpurea* sclerotia. Fifty sclerotia collected from perennial ryegrass and Kentucky bluegrass were placed in nylon mesh bags and buried at a depth of 0.7 inch at ten different locations in a commercial perennial ryegrass field (PRG) and Kentucky bluegrass (KBG) field in Hermiston, OR and Madras, OR, respectively. After 1 month in the field, sclerotia were retrieved, washed, and cultured on either potato dextrose agar or nutrient agar media. In addition, for direct isolation, sclerotia obtained from commercial grass seed cleaning facilities were cultured in a similar manner.

Fungi and bacteria were isolated and identified using morphological and molecular tools. Isolates of *Epicoccum nigrum*, *Pantoea agglomerans*, *Pseudomonas putida*, and *Pseudomonas brassicacearum* were selected for screening based on their ability to inhibit sclerotia germination as documented in the scientific literature. Spore suspensions (10^9 CFU/ml) were produced by filtering pure liquid cultures of the isolates mentioned above through four layers of sterile cheesecloth or by washing spores from actively growing petri plates using sterile water.

The screening assay consisted of petri plates containing 20 g of autoclaved soil and 20 surface-sterilized sclerotia that were preconditioned in moist sterile soil at 41°F for 6 weeks to simulate vernalization and break dormancy. All treatments, consisting of *Epicoccum nigrum*, *Pantoea agglomerans*, *Pseudomonas putida*, *Pseudomonas brassicacearum,* and a water control, were replicated four times. Treatments were made using a hand-held sprayer, and plates were incubated at 60°F for 7 weeks after treatment. The number of parasitized and germinated sclerotia observed in each treatment was compared to the parasitized and germinated sclerotia of the water-treated control. Data were analyzed using ANOVA and means separated using Tukey's test.

Evaluation of commercial biocontrol products against sclerotia germination

A laboratory assay was conducted to evaluate the efficacy of commercially available biocontrol products, including Contans (*Coniothyrium minitans*; Advan LLC, Roswell, GA), Trichopel (*Trichoderma harzianum*; Agrimm Tech Ltd, Christchurch, NZ), SoilGard (*Gliocladium virens*; Certis USA LLC, Columbia, MD), and Serenade (*Bacillus subtilis*; Bayer CropScience, Research Triangle Park, NC) to inhibit sclerotia germination (Table 1).

This test consisted of 25 perennial ryegrass sclerotia placed on 25 g of sterilized soil contained in a petri dish.

Table 1. Trade name, active ingredient, concentration, formulation type, and application rates of commercial biocontrol products used in laboratory assays, 2016.

Trade name	Active ingredient and concentration	Formulation type	Rate
			(product/unit area)
Contans	*Coniothyrium minitans* (1 x 10^9 CFU/g)	Wettable granules	1.8 lb/a
Trichopel	*Trichoderma harzianum* (1 x 10^6 CFU/g)	Granular	9.8 lb/1,000 ft^2
SoilGard	*Gliocladium virens* strain GL-21 (1 x 10^6 CFU/g)	Granular	4 oz/1,000 ft^2
Serenade	*Bacillus subtilis* strain QST 713 (1 x 10^9 CFU/g)	Liquid	192 oz/a

Treatments were arranged in a randomized complete block design and replicated four times. Sclerotia were preconditioned in moist sterile soil at 41°F for 6 weeks during spring of 2016. Treatments were applied at labeled rates, and the sclerotia were incubated at 60°F for 7 weeks. The numbers of germinating sclerotia and fruiting bodies (capitula) were noted for area under capitula production curve (AUCPC) calculations, and data were analyzed using ANOVA.

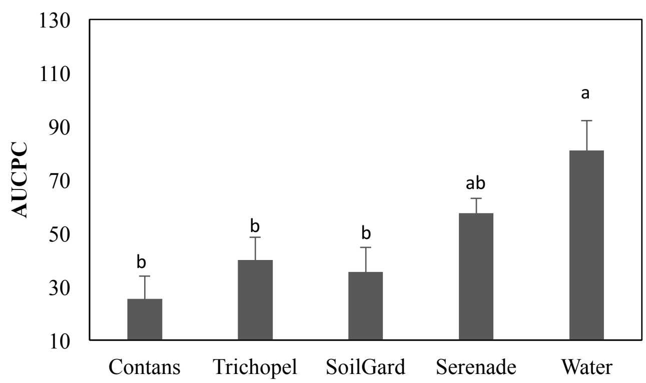

Figure 1. Mean area under capitula production curve (AUCPC) values in experimental petri plates containing ergot sclerotia treated with various biocontrol fungicides.

Results and Discussion

Isolation and screening of fungi and bacteria on *C. purpurea* sclerotia

The microflora isolated from the baited ergot sclerotia in Hermiston, OR and Madras, OR were a complex of fungi, including *Fusarium* species (most commonly *Fusarium avenaceum* and *F. incarnatum*), *Pythium* spp., *Alternaria* spp., *Epicoccum nigrum*, and zygomycetes. Isolated bacteria included members of the Enterobacteriaceae family, namely *Pantoea* spp. and *Erwinia* spp., as well as members of the *Pseudomonas* spp. complex. Interestingly, the genera and species of microflora isolated from baited sclerotia were similar between the Columbia Basin and central Oregon. Unfortunately, culture filtrates of the selected microorganisms did not inhibit ergot sclerotia germination. In addition, many of these organisms are potential plant pathogens, which would limit their use as biocontrol options for ergot.

Evaluation of commercial biocontrol products against sclerotia germination

Laboratory assays resulted in significant reductions in AUCPC ($P = 0.0008$) after treatment with Contans, Trichopel, and SoilGard, compared to the water-treated control plates (Figure 1). Application of Contans reduced AUCPC values by 68.5%, compared to the control, while Trichopel and SoilGard reduced AUCPC values by 55.6 and 50.6%, respectively. Contans has been reported as an effective sclerotial mycoparasite in a variety of crops (Whipps et al., 2008). Antagonistic activities were previously reported for products containing *Trichoderma viride*, *Trichoderma harzianum*, and *Gliocladium virens* against sclerotia germination of *Claviceps fusiformis* (Mohan and Jeyarajan, 1990).

Conclusion

Diverse plant pathogenic and saprophytic microorganisms were found to be associated with *C. purpurea* sclerotia in commercial grass seed production fields. However, none of these was observed to be a mycoparasite of ergot. On the other hand, some commercial biocontrol products that are labeled for management of other sclerotia-producing fungi were found to reduce sclerotia germination in laboratory assays. Additional testing of these products is currently underway in field trials located at Hermiston Agricultural Research and Extension Center, Hermiston, OR.

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SPATIAL VARIABILITY IN SLUG EMERGENCE PATTERNS—THIRD-YEAR RESULTS

G.W. Mueller-Warrant, N.P. Anderson, C.S. Sullivan, and K.M. Trippe

Introduction

Slugs remain widely viewed as serious pests of many Willamette Valley crops, including grasses grown for seed, especially during the establishment of new fall plantings. Objectives of this project were to monitor the timing of slug emergence and evaluate the feasibility of identifying areas within fields with highest populations of slugs to help focus control efforts on situations with the greatest risk of crop damage. Fall 2016 was the third year of ongoing research, and this report focuses on results from that year, along with comparisons among 2014, 2015, and 2016.

Material and Methods

Tests were conducted during grass seedling establishment of four major crop rotations (Table 1): red clover followed by conventional tillage fall planting of new perennial ryegrass (PR) stands, (2) white clover followed by no-till fall planting of PR, (3) winter wheat followed by conventional tillage fall planting of PR, and (4) canola followed by conventional tillage fall planting of PR.

Weekly counting of slugs, predatory beetles, and earthworms began just prior to crop emergence, except at site 1, where irrigation allowed the crop to emerge in mid-September, 3 weeks prior to our first counts. At all sites, slug blankets were placed in grid patterns spaced at approximately 1 acre per blanket, with a minimum of 36 locations per field. Ground chicken mash was applied beneath each water-soaked blanket on one day, and slugs, worms, and beetles were counted the next day. Plywood squares (16 inches x 16 inches) were used to cover the slug blankets to prevent disturbance by wind or water and to help maintain moisture within the blankets.

Slugs were counted weekly from October to December, and less frequently after that, for a total of 10, 9, 8, and 7 times at sites 1, 2, 3, and 4 (Table 1). In general, growers had fewer problems getting on their fields to apply slug bait in 2016 than they had in either of the 2 previous years. Timing of slug counts in this report refers to the number of weeks since early October, with week 1 being the period from October 2 to October 8, 2016. Experiments were terminated once crops were well established and final counts of crop stands and slug densities had been taken in late winter. Unusually heavy rainfall in October 2016 interfered with growers' plans for planting, with planting delayed until October 20 at site 3 and November 9 at site 4. Unusually warm weather lasted until the first week of December, facilitating vigorous growth of PR planted before the deluge. Late-planted stands suffered from the prolonged periods of cold weather in December and January.

Methods explored to quantify the spatial distribution of slugs and crop damage were similar to those used in previous years. The Gi-star hot spot analysis technique was chosen because it provided useful information on

Table 1. Slug emergence study site descriptions, fall 2016.

Site no.	County	Previous crop	Seedbed preparation	Planting date	Number of slug counts	Slug bait application dates
1	Linn	Red clover	Conventional tillage, irrigated up	Sep. 15	10	Oct. 28
2	Linn	White clover	No-till	Sep. 28	9	Oct. 18 Nov. 1 Nov. 15 Nov. 29
3	Polk	Wheat	Conventional tillage	Oct. 20	8	Nov. 8 Nov. 29
4	Polk	Canola	Conventional tillage	Nov. 9	7	Nov. 10 Nov. 29 Dec. 21

the statistical significance of slug populations. “Hot spots” denote locations with consistently higher-than-expected counts, and “cold spots” are those with lower-than-expected counts.

Soil moisture was measured gravimetrically using surface 2-inch-deep soil samples taken each time slugs were counted. Crop stands were evaluated by counting the number of missing 1-inch sections of row per 260 feet of row at each plot in a rectangle around the target flag, skipping the center 10 feet x 9 feet because of soil sampling disturbance and crop damage under the slug blankets. Slug baits were applied by growers based on their own experience and on information we provided to them regarding weekly slug counts.

Results and Discussion

Soil moisture content at the two early-planted sites (conventional tillage following red clover and no-till following white clover) was approximately 26% on October 12, resulting in rapid emergence of PR seedlings at site 2; those at site 1 had emerged even earlier due to use of irrigation in mid-September. Critical soil moisture content for PR emergence during the two previous falls had been a similar minimum of greater than 25%. All subsequent soil moisture readings in fall of 2016 were in a range of 35 to 40%, except at site 3, where the sandier soil was in a range of 31 to 34% soil moisture. The warm, moist conditions in October and November of 2016 not only encouraged rapid growth and development of PR seedlings, but also resulted in the appearance of more slug egg masses in the fields than in either of the 2 previous years.

Predatory beetle populations were highest in the first few weeks of counting at any site, declining slowly until the arrival of snow and freezing temperatures in December (Table 2). Numbers of predatory beetles varied widely among the sites, perhaps responding to prior crops or differences in insecticide use patterns. Earthworm counts were lower than in either of the 2 previous years. The no-till site had low numbers of predatory beetles and high numbers of earthworms, while numbers of beetles and earthworms varied widely among the three conventionally tilled sites.

As in previous years, slugs were not uniformly distributed across any of the sites on any single date. Counts varied from 0 to 76 slugs per blanket. There were, however, fewer differences over time in 2016 than in 2015. In general, counts were also more stable over time in 2015 than in 2014. Consistent spatial patterns in slug counts occurred at all four sites in 2016.

At site 1, the earliest planted field, both hot spots and cold spots were statistically significant, with consistently higher-than-average slug counts at two hot spots and consistently lower-than-average counts at three cold spots (Figure 1). The cold spots all occurred along the east edge of the field and may represent border effects. Although the two hot spots were both on the north edge of the field, nothing else stood out as unique about those locations.

There were three statistically significant hot spots at site 2, all near the southeast corner of the field and close to the base of a large, nearby hill (Figure 2). This suggests the possibility that subsurface moisture flow over the summer draining from the adjacent hillside could have facilitated more vigorous growth by the white clover crop, thereby benefiting the slugs. Slug counts over time were more uniform at this site than

Table 2. Slug emergence, predatory beetle, and earthworm results for each study site, fall 2016.

Site no.	Average weekly slug count, entire fall season	Highest weekly --- average slug counts ---		Slug counts from period most likely ----- related to crop loss ----		Average counts ----------- of other organisms[2] -----------	
		Week[1]	Average number	Weeks included	Average number	Predatory beetles (weeks 3–9)	Earthworms (weeks 4–9)
1	3.5	4	11.3	3–4	8.8	0.03	0.9
2	7.4	7	8.8	2–7	7.2	<0.01	4.3
3	1.4	7	3.2	5–8	1.9	0.52	4.5
4	8.4	8	18.2	7–10	9.8	2.73	0.3

[1]Week 1 of fall establishment season was defined as October 2–8, 2016, even though the crop had emerged 3 weeks earlier at site 1 due to use of irrigation.

[2]Counts did not begin until weeks 5 and 7 at sites 3 and 4, respectively, due to delayed planting.

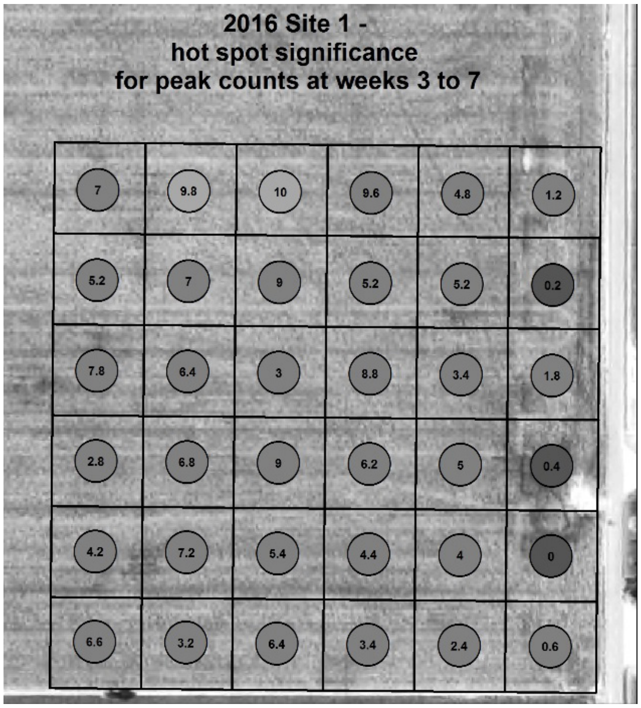

Figure 1. Hot and cold spots for slug counts at site 1.

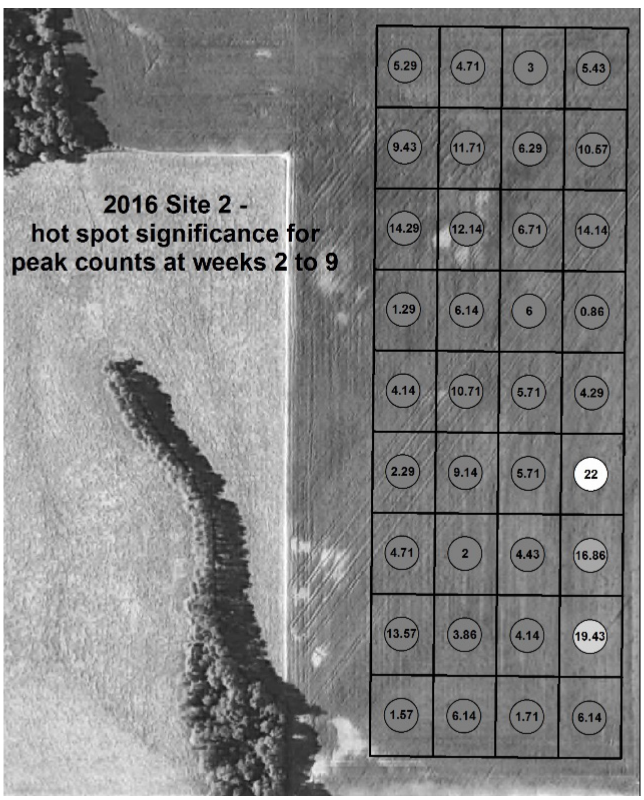

Figure 2. Hot spots for slug counts at site 2.

at the other three sites, likely due to the generally favorable conditions for slugs in no-till white clover, a phenomenon seen in the previous 2 years. Slug baits were applied by growers more often at site 2 than at the three other sites.

There were four statistically significant hot spots at site 3, with three of them occurring on the south side of our plots, a position in the field at which elevation dropped off markedly in the general slope from north to south (Figure 3). This lower elevation region of the field may have experienced greater subsurface moisture flow during the summer than the slightly higher elevation region to the north. No obvious cause for the hot spot in plot 313 could be discerned.

All four statistically significant hot spots at site 4 occurred on the south side of our plots in the lower elevation portion of the field (Figure 4). Complex water flow patterns were present in this field, with multiple small springs running throughout the period of slug counts. The prior crop of canola appeared to be quite favorable for slugs, and counts in some of the plots at this site were among the highest ever recorded in our research over the past 3 years.

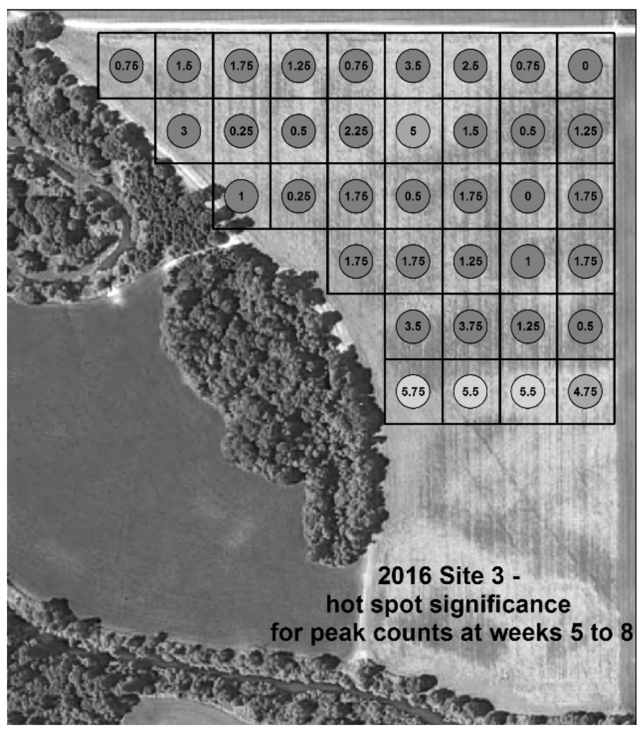

Figure 3. Hot spots for slug counts at site 3.

Note: For Figures 1–4, values within circles are the average peak slug counts, with statistical confidence levels of 99% for fully white circles (hot spots) or black circles (cold spots), 95% for mostly white or black circles, 90% for slightly white or black circles, and nonsignificance for neutral gray circles.

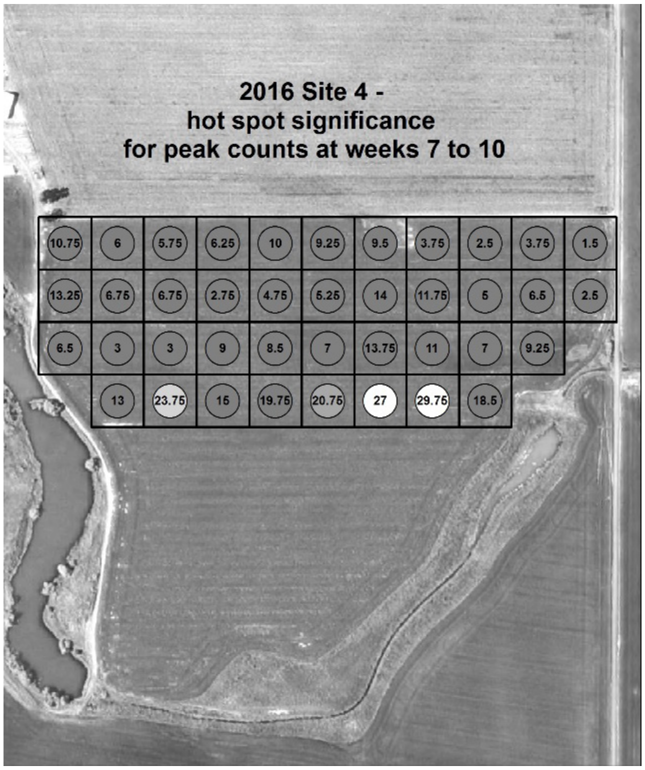

Figure 4. Hot spots for slug counts at site 4.

To test the hypothesis that shallow subsurface moisture was a critical factor in successful over-summer survival by slugs, we conducted deep soil sampling in late summer of 2016 at the site that had the strongest spatial patterns in slug counts in 2015. We sampled soil to a depth of 3 feet, compositing the soil into 6-inch increments. There were differences among plots in the moisture content of the two deepest depths (24–30 inches and 30–36 inches). However, these differences did not align meaningfully with the slug counts from 2015. It seems likely that favorable subsurface soil moisture may be a necessary but not sufficient condition for the presence of high slug counts. High among the other possible factors is simply how well the slugs did versus any slug bait applications in the recent past.

All evidence from the past 3 years of slug counts indicates that slugs tend to live out their lives within a few hundred feet of where they hatched, and that acre-size plots are large enough to be nearly independent of one another.

Crop damage by slugs was relatively mild during the fall of 2016, and ongoing counts of PR stands indicate that both fields planted before heavy rains in October established quite well.

Performance of slug bait applications varied widely among sites, with two-fold reductions in slug counts at site 2 (e.g., eight slugs per blanket the week before treatment and four slugs per blanket the week after treatment) and seven-fold reductions at site 1. Interactions between temperature, planting date, and timing of slug bait applications at the other two sites prevented us from estimating performance of slug bait applications.

The critical period for crop damage caused by slugs was spread over a wider period in the fall of 2016 than in previous years because of the range in planting dates caused by interruption of field work by heavy rainfall in October. As a result, only at site 2 was it possible to correlate crop damage with slug counts.

Summary

These findings have several important implications for management of slugs by grass seed growers. First, the absence of cold spots, except at a single site in 1 year (site 1 in 2016), means that entire fields will generally need to be treated at least once during the peak emergence of slugs after fall rains begin; there were no truly safe locations free of all slug danger. Second, the presence of several stable hot spots at each of the sites means that there will be areas needing repeated applications of slug bait. The simplest way to identify those areas would be to mark locations where high numbers of slugs have already been found. Third, the multiyear correlation between lower elevations and higher slug counts within fields suggests that it may be possible to predict where slug numbers will be highest within fields. Fourth, no-till establishment of PR into existing clover crops can succeed if growers are willing to apply slug bait multiple times over the fall (i.e., whenever more slugs appear at the soil surface ready to eat crop plants) and are diligent in their scouting for slugs. Fifth, the economic threshold for damage to PR seedlings remains very low, likely somewhere between two and four slugs per blanket for measurements made during active slug baiting. The threshold would likely be even lower if slug bait was never applied.

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PLANT GROWTH REGULATOR AND IRRIGATION EFFECTS ON WHITE CLOVER SEED CROPS

N.P. Anderson, T.G. Chastain, and C.G. Garbacik

Introduction

Forage legume seed crops, including white clover grown for seed, are a vital part of seed production enterprises and valuable rotation crops for grass seed crops grown in Oregon. While white clover seed crop acreage has increased dramatically over the past decade in Oregon, seed yields harvested by growers have shown smaller increases over that period, compared to red clover and crimson clover seed crops. Recent work has demonstrated that trinexapac-ethyl (Palisade EC) plant growth regulator (PGR) is a key tool for increasing seed yield in red clover (Anderson et al., 2015; Øverland and Aamlid, 2007). This 2-year study was undertaken to determine whether trinexapac-ethyl and paclobutrazol (Bonzi) PGRs can also be utilized to further improve seed yield in white clover.

Seed yield in white clover seems to be related to the number of inflorescences (heads) per unit area. Inflorescences arise in the leaf axils of stolons (horizontal above-ground stems). To maximize the production of inflorescences, the stolons need unshaded space in which to grow. Moreover, the indeterminate habit of white clover means that there is a broad period of flowering with no definitive peak, so the timing of management practices to enhance seed yield is more difficult than in other vertically elongated clover species.

The most widely tested PGR in white clover seed production has been paclobutrazol. Previous results with paclobutrazol have been variable. When paclobutrazol is effective, however, seed yield increases have been encouraging. More recently, trinexapac-ethyl has received some attention in white clover seed crops in New Zealand, but most reports indicate that seed yield responses have not been as beneficial as in red clover (Chakwizira et al., 2011). No information is available on the responses of white clover seed crops to paclobutrazol or trinexapac-ethyl PGRs under Oregon conditions.

Irrigation research has shown mixed effects on seed yield in white clover, and therefore irrigation is not widely practiced in the Willamette Valley. However, growers have expressed interest in seeing more research data on the effects of irrigation in white clover seed production. Oliva et al. (1994) suggested that irrigation could increase white clover seed yield in western Oregon, but there is a need to control the excessive development of stolons in response to irrigation. One aim of this study was to determine whether PGRs could be used as a tool to manipulate the development of stolons in irrigated stands by reducing the internode length, thus providing a better environment for flowering and improved seed yield.

Materials and Methods

Field plots were established with ladino (VNS) white clover at OSU's Hyslop Farm in the fall of 2014 and followed for two seed harvests (2015 and 2016). The experimental design for the trials was a randomized complete block with a split-plot arrangement of treatments and four replications. Main plots were irrigation treatments, and subplots were PGR products and rates. The PGR subplots were randomly allocated within irrigation main plots.

Irrigation main plots included:

- No irrigation
- Irrigation (4 inches)

PGR subplots included the following products and rates in 2015 and 2016:

2015

- Palisade EC (4.3 pt/acre)
- Palisade EC (5.7 pt/acre)
- Bonzi (0.89 lb ai/acre)

2016

- Palisade EC (2.15 pt/acre)
- Palisade EC (4.3 pt/acre)
- Bonzi (0.89 lb ai/acre)

Plot size was 11 feet x 50 feet. One strategically timed application of irrigation was carried out on irrigated white clover treatments during early flowering. Above-ground biomass was taken from plots near crop maturity, and total above-ground biomass was determined. Inflorescence number was ascertained near peak flowering.

Seed was harvested with a small-plot swather and combine, and seed yield was determined on the cleaned seed. Seed weight was determined by counting two 1,000-seed samples with an electronic seed counter and weighing these samples on a laboratory balance. Harvest index, the ratio of seed yield to above-ground biomass, was also measured.

Results and Discussion

Irrigation had no effect on seed yield, but increased seed weight in both years (Tables 1 and 2). In the first-year stand (2015), application of Palisade EC decreased seed yield and seed weight (Table 1). The high rates of Palisade EC seemed to have phytotoxic effects on the foliage. Palisade EC rates were reduced in the second year, and there was no effect on seed yield, although seed weights still decreased compared to the control (Table 3). Cleanout was not affected by irrigation or PGRs in either year.

Aside from seed weight, irrigation had no effect on any of the seed yield components measured in either year (Tables 3 and 4). In the first-year stand (2015), neither PGR affected dry weight or number of inflorescences (Table 3). However, Palisade EC increased florets per inflorescence. Bonzi had no effect. Irrigation had no effect on harvest index, while PGRs had mixed effects. In the second-year stand (2016), Bonzi had no effect

Table 1. Seed yield, percent cleanout, and 1,000-seed weight measurements following PGR applications applied at stem elongation in irrigated and nonirrigated environments, 2015.[1]

	Yield	Cleanout	Seed weight
	(lb/a)	(%)	(mg seed^{-1})
Irrigation			
Irrigated	487	9.8	0.57 b
Nonirrigated	494	10.4	0.54 a
Treatment			
Control	557 b	10.8	0.59 c
Palisade EC 4.3 pt/a	424 a	10.6	0.51 b
Palisade EC 5.7 pt/a	400 a	11.1	0.50 a
Bonzi 0.89 lb ai/a	560 b	8.7	0.59 c

[1]Means followed by the same letter are not different at LSD ($P = 0.05$).

Table 2. Seed yield, percent cleanout, and 1,000-seed weight measurements following PGR applications applied at stem elongation in irrigated and nonirrigated environments, 2016.[1]

	Yield	Cleanout	Seed weight
	(lb/a)	(%)	(mg seed^{-1})
Irrigation			
Irrigated	481	8.0	0.59 b
Nonirrigated	458	6.2	0.57 a
Treatment			
Control	494	7.2	0.60 c
Palisade EC 2.15 pt/a	474	7.4	0.57 b
Palisade EC 4.3 pt/a	443	7.2	0.54 a
Bonzi 0.89 lb ai/a	449	6.4	0.60 c

[1]Means followed by the same letter are not different at LSD ($P = 0.05$)

Table 3. Seed yield component measurements following PGR applications applied at stem elongation in irrigated and nonirrigated environments, 2015.

	Dry weight	Inflorescences	Florets[1]	Harvest index[1]
	(g/m^{-2})	(number/m^{-2})	(number/inflorescence)	(%)
Irrigation				
Irrigated	748.3	636.7	85	7.5
Nonirrigated	651.6	607.7	85	8.8
Treatment				
Control	760.2	605.3	80 a	8.6 bc
Palisade EC 4.3 pt/a	666.9	616.0	92 b	7.4 ab
Palisade EC 5.7 pt/a	694.7	632.8	89 b	6.6 a
Bonzi 0.89 lb ai/a	694.2	623.4	82 a	9.5 c

[1]Means followed by the same letter are not different at LSD ($P = 0.05$)

Table 4. Seed yield component measurements following PGR applications applied at stem elongation in irrigated and nonirrigated environments, 2016.

	Dry weight	Inflorescences[1]	Florets	Harvest index[1]
	(g/m^{-2})	(number/m^{-2})	(number/inflorescence)	(%)
Irrigation				
Irrigated	783.1	741	74	7.1
Nonirrigated	672.8	742	77	8.7
Treatment				
Control	747.0	699 ab	75	8.6 b
Palisade EC 2.15 pt/a	771.5	845 c	75	6.6 a
Palisade EC 4.30 pt/a	723.5	800 bc	80	6.3 a
Bonzi 0.89 lb ai/a	717.4	689 ab	75	9.1 b

[1]Means followed by the same letter are not different at LSD ($P = 0.05$)

on any yield components, but TE increased numbers of inflorescences/m^2 (Table 4). Unfortunately, this increase did not influence seed yield. PGRs had no effect on floret number in the second-year stand.

Results from this 2-year trial indicate that irrigation and PGRs do not influence seed yield of white clover crops grown in western Oregon. Therefore, we do not recommend either practice on commercial fields at this time.

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TRINEXAPAC-ETHYL TIMING AND RATE EFFECTS ON CRIMSON CLOVER SEED PRODUCTION

M. Morad, T.G. Chastain, N.P. Anderson, and C.J. Garbacik

Introduction

Crimson clover is one of the important forage legume seed crops grown in the Willamette Valley of Oregon. The Willamette Valley produces about 95% of the total U.S. crimson clover seed crop annually, with production valued at $20 million in 2014.

Crimson clover seed yields have more than doubled since the mid-1970s, and recent research with red clover seed crops suggests that further improvement of crimson clover seed yield may be possible. One reason for increased red clover seed yield is foliar application of the plant growth regulator (PGR) trinexapac-ethyl (TE), an anti-lodging agent (Øverland and Aamlid, 2007; Anderson et al., 2015; Anderson et al., 2016).

Research focused on application of TE or any other PGR to crimson clover seed crops has not previously been conducted. Preliminary on-farm trials have shown that TE can increase crimson clover seed yield by 10–24% over the untreated control (Anderson et al., unpublished). More information is needed to identify the optimum application rate and stage of crop development for TE application to achieve the best economic return in crimson clover seed production.

The objective of this 2-year study was to evaluate the effects of TE timing and application rate on crimson clover seed crops and to establish recommendations for timing of TE application to crimson clover in the Willamette Valley of Oregon.

Materials and Methods

Field trials were established at Hyslop Research Farm near Corvallis, OR, for the 2014–2015 and 2015–2016 crop years. Crop development stages and crop management timings were assessed using the BBCH scale. Crimson clover seed was planted in October 2014 and 2015 with a Nordsten drill set at a 6-inch row spacing. The seeding rate was 17 lb/acre. SelectMax (Clethodim) and MCP Amine 4 (MCPA) herbicides were applied at 12 oz/acre and 10 oz/acre, respectively, at BBCH 12 to control weeds in the crop. The crimson clover crop was mowed to a height of 5 inches at BBCH 40 to control a wild garlic (*Allium vineale*) infestation during the second year.

The experimental design was a randomized block design with four replications. TE was applied at two stages of crop development: stem elongation (BBCH 32, late March) and bud emergence (BBCH 50, mid-April). At each application timing, four TE rates were applied (1, 2, 3, and 4 pt product/acre). Visual evaluations were conducted on date1, date2, etc. to determine the effect of TE rate and application timing on crop growth and development compared to an untreated control.

Soil water content was determined by time domain reflectometry (TDR) in early May. Seed yield components, including numbers of stems, heads, and florets, were quantified on samples taken at peak bloom (BBCH 65, mid-May). Canopy characteristics, including above-ground biomass and canopy height, were also measured at peak bloom.

The crimson clover was swathed with a modified John Deere 2280 swather, and seed was harvested with a Hege 180 plot combine in June 2015 and June 2016, respectively. The seed was cleaned with a M2-B Clipper seed cleaner, and 1,000-seed weight was recorded after counting with an Old Mill Company Model 850-2 seed counter. Seed number/ft^2 was calculated based on seed yield and 1,000-seed weight values obtained from each plot. Analysis of variance (ANOVA) was used to test TE treatment effects, and Fisher's protected least significant difference (FPLSD) test was used to separate treatment means.

Results and Discussion

ANOVA revealed that crimson clover stem numbers, above-ground biomass, seed head numbers, seed number, and seed yield were not affected by application of TE PGR (Table 1). Very dry conditions prevailed in the spring of 2015, with only 58% of normal rainfall occurring April through June, and these dry conditions likely influenced the results. Extremely wet conditions were prevalent in the 2015–2016 crop year, especially in fall 2015 (132% of normal rainfall) and March 2016 (183% of normal rainfall).

In 2015, seed yields were variable and were lower than the 10-year average yield of 910 lb/acre for the Willamette Valley as a result of extreme drought and high temperatures during the 2014–2015 crop year

(Table 2). Neither timing of TE PGR application nor application rate affected seed yield. These results were inconsistent with the preliminary on-farm trials in prior years, which showed a seed yield increase with TE. Table 2 shows seed yield and the contributions of its two primary seed yield components, seed weight and seed number. Seed yield is the mathematical product of yield components and can be expressed as follows: seed yield/area = seed weight x seed number/area. Seed weight was reduced with all TE application treatments (Table 2). Overall, seed weight generally declined with increasing rate of TE and later application time. There was no effect of TE on seed number, which was the primary factor responsible for the seed yield increase by TE PGR in red clover (Anderson et al., 2015; Anderson et al., 2016).

Wet fall and late spring conditions in the 2015–2016 crop year resulted in poor stands and low seed yields in 2016 (Table 2). Seed yields were not influenced by TE in 2016. Nevertheless, seed weight was affected by TE in the same way in 2016 as in 2015, despite the lack of influence on seed yield. In general, seed weight was reduced by TE, and that effect was most pronounced at high TE rates. Unlike in 2015, seed number was affected by TE. Seed number was increased by TE with application rates of 2–4 pt/acre at the BBCH 32 timing and by 3-4 pt/acre TE at the BBCH 50 application timing. This increase in seed number was unable to offset the loss in seed weight, thereby resulting in no seed yield increases by TE.

Canopy height of the crop was consistently reduced with TE applications in 2015 and in 2016 (Table 3). Biomass and harvest index were not affected by TE application in either year (data not shown). The number of florets increased at the BBCH 32 application timing with 1–3 pt/acre, but not with 4 pt/acre in 2015. Only the 3 pt/acre rate increased floret production at the BBCH 50 timing. No effects of TE on stem number, inflorescence number, or floret number were quantified in 2016. Cleanout increased with 3 and 4 pt/acre of TE at the BBCH 50 timing in 2015, but not in 2016.

Table 1. ANOVA for trinexapac-ethyl treatment effects on crimson clover seed yield and seed yield components, 2015 and 2016.[1]

Characteristics	2015	2016
Seed yield	ns	ns
Seed weight	***	***
Seed number	ns	***
Cleanout	***	ns
Biomass	ns	ns
Stems/ft^2	ns	ns
Heads/ft^2	ns	ns
Florets/ft^2	*	ns
Canopy height	***	***
Soil water content	*	ns

[1]* $P \leq 0.05$
** $P \leq 0.01$
*** $P \leq 0.001$
ns = Not significant

Table 2. Effect of trinexapac-ethyl timing and rate on seed yield and primary seed yield components (seed weight and seed number) in crimson clover.[1]

---------- Treatment ----------		------ Seed yield ------		------ Seed weight ------		------ Seed number ------	
Timing	Rate	2015	2016	2015	2016	2015	2016
	(pt/a)	------- (lb acre^{-1}) -------		------- (mg seed^{-1}) -------		------- (seeds ft^{-2}) -------	
Untreated control	—	362 a	287 a	5.67 a	5.24 a	667 a	559 ab
BBCH 32	1	346 a	304 a	5.38 b	4.98 b	673 a	624 abc
	2	364 a	291 a	5.17 c	4.48 d	733 a	660 cd
	3	383 a	331 a	5.05 cd	4.42 de	792 a	763 e
	4	305 a	299 a	4.79 de	4.24 e	669 a	717 de
BBCH 50	1	278 a	267 a	5.11 c	4.98 b	566 a	547 a
	2	301 a	294 a	4.88 de	4.74 c	643 a	631 bc
	3	290 a	307 a	4.49 f	4.37 de	676 a	716 de
	4	278 a	289 a	4.38 f	4.36 de	660 a	675 cd

[1]Means followed by the same letter within each column are not significantly different by Fisher's protected LSD values (P = 0.05).

Table 3. Trinexapac-ethyl timing and rate effects on canopy height in crimson clover, 2015 and 2016.[1]

Treatment		Canopy height	
Timing	Rate	2015	2016
	(pt/a)	(cm)	
Untreated control	—	71.1 a	69.1 a
BBCH 32	1	61.1 bc	61.1 bc
	2	58.3 cd	54.1 de
	3	55.7 d	56.7 cd
	4	53.6 d	51.7 e
BBCH 50	1	65.2 b	63.1 b
	2	63.9 b	57.3 cd
	3	63.8 b	56.8 cd
	4	62.4 bc	53.4 de

[1]Means followed by the same letter within each column are not significantly different by Fisher's protected LSD values ($P = 0.05$).

Cleanout represents the quantity of nonseed material harvested.

The reduction in canopy height by TE most likely opened up the canopy, thereby allowing a greater loss of soil water through evaporation in 2015. Coupled with the abnormally dry and hot conditions in 2015, the reduction in canopy coverage with TE reduced the amount of soil water available for seed filling; as a result, seed weight was also reduced more than previously noted. With very wet conditions in March and April 2016, no effects of TE on soil water content were detected in early May 2016.

Poor weather and growing conditions in both years of the study resulted in lower-than-expected seed yields for crimson clover. Under these extreme conditions, TE consistently reduced height of the crimson clover seed crop canopy. Although seed yield was not affected, seed weight was reduced at all rates and timings.

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INVESTIGATING THE IMPACT OF ROW SPRAYING ON ESTABLISHED WHITE CLOVER

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Introduction

White clover seed producers in the Willamette Valley struggle with highly variable yields from year to year. Seed yield is most dependent on flower head density, which in turn is affected by environment, management, and cultivars (FAR, 2006). In Oregon, white clover seed yields vary widely due to the difficulty in managing crop vigor with grazing and to variability in weather. Researchers in New Zealand have managed to increase clover seed yield and stability by refining the timing of sheep removal from the field and through irrigation practices, row spacing, and management of second-year clover growth with herbicides.

White clover spreads by stolons. Flowers are produced on the tip of a stolon as long as the stolon continues to grow outwards; therefore, creating space for stolon elongation is deemed a critical factor contributing to seed yield. Second-year growth needs to be "managed" (reduced) to create space for growth of primary stolons, which produce the most seed heads.

Optimal production of primary stolons is difficult to manage with grazing alone, as over-grazing leads to high production of secondary and tertiary stolons. These later-developing stolons are less likely to produce seed and thus reduce yield (Clifford, 1980). In New Zealand, herbicides have long been used in second-year crops to reduce stolon density. More recently, row spraying with herbicides has been used to optimize primary stolon number and length, as well as flower density (Thomas et al., 2009).

Growers are aware that Willamette Valley growing conditions are different than those in New Zealand. However, they are interested in the feasibility of row spraying in rainfed white clover seed production systems. Several growers in the Willamette Valley have experimented with row spraying in established white clover stands (Aldrich-Markham, 2011), but no measurable data have been collected to quantify impacts on seed yield. Herbicides and timing of application need to be evaluated in order to determine whether row spraying is a viable tool for local seed producers.

The goal of this research was to evaluate the effectiveness of row spraying in second-year white clover stands in the Willamette Valley. More specifically, the objectives were to: (1) evaluate herbicides for row spraying white clover based on row formation, row persistence, clover crop tolerance, and clover seed yield; and (2) evaluate different row spray application timings to determine the optimal timing window to achieve maximum flower head density and seed yield.

Materials and Methods

The trial was conducted in 2016 on a second-year stand of ladino-type white clover (VNS) established at Hyslop Research Farm in the fall of 2014. The clover stand was not fertilized in 2016, and no pesticide applications outside of the herbicide treatments were made during the growing season. Field sweeps were conducted for white clover seed weevils, but weevil numbers were well below the threshold for an insecticide application. Beehives were present at a nearby trial, and bees were seen actively foraging in the plots.

The trial was arranged as a randomized complete block design with four replications of each treatment. Plot size was 8 feet x 30 feet. A bicycle sprayer was used to apply eight herbicide treatments (Table 1) at three

Table 1. Herbicide treatments used for row spraying in established white clover stands. ***Note***: None of the listed herbicide treatments is currently labeled for use in white clover grown for seed.

Treatment	Active ingredient	Rate
		(lb ai/a)
Control	—	—
Alion + Rely	Indazaflam + glufosinate	0.0196 + 0.88
Express	Tribenuron	0.0078
Goal[1]	Oxyfluorfen	0.0625
Rely	Glufosinate	0.88
Sharpen	Saflufenacil	0.0445
Sharpen broadcast	Saflufenacil	0.0445
Chateau	Flumioxazin	0.128

[1]Goal is labeled for use as a dormant application, but is not labeled for row spraying use.

timings in the late winter/early spring of 2016: "early timing" (February 22), "mid timing" (March 30), and "late timing" (May 18). In total, there were 24 treatment combinations per replicate. The sprayer was set up to create a 4-inch white clover row by spraying out an 8-inch band using six nozzles (40 03) mounted to the boom at 12-inch spacing. Sheep did not graze the field, and the trial site was flail mowed April 25 and May 11 to manage crop height. (Crop residue was left in the field.)

Visual evaluations of row persistence and crop injury were made six times between March 17 and June 21. Flower head density was measured by counting the number of flowers in two 0.5 m^2 quadrats per plot on May 5, June 18, and July 17. Plots were cut and raked into swaths on July 18. Seed was harvested with a plot combine on July 29. Seed was cleaned with a clipper cleaner, and seed yield was determined.

Results and Discussion

Visual evaluations conducted on May 30 showed low row persistence and low crop injury in many of the early and mid application plots (Figure 1). Early applications of Goal and Chateau resulted in negligible crop injury and short-term row persistence. On the other hand, late row spraying resulted in unacceptable crop injury.

Flower head density counts taken just before swathing on July 17 revealed very similar flower head densities between the control plots and herbicide treatments applied early and mid (Table 2). None of the treatments evaluated in the trial produced significantly higher flower density than the control (31 flowers/ft^2). However, average flower head density was significantly reduced in the late treatments (20 flowers/ft^2).

Overall, seed yields were very low (0–200 lb/acre), due to equipment challenges during harvest. Seed was lost during both swathing and combining. The yields in this trial are not representative of typical white clover seed yields. However, all plots were treated the same, and results within the trial can be compared relative to each other. Some of the treatments with high flower head density, such as Goal and Chateau at early and mid timings, also had high seed yields, but none was significantly higher than the control plots (Table 3). Overall, yield in the control plots (154 lb/acre) was significantly higher than in the early (102 lb/acre) and mid (99 lb/acre) application timings. These application timings produced higher yields than the late application (31 lb/acre).

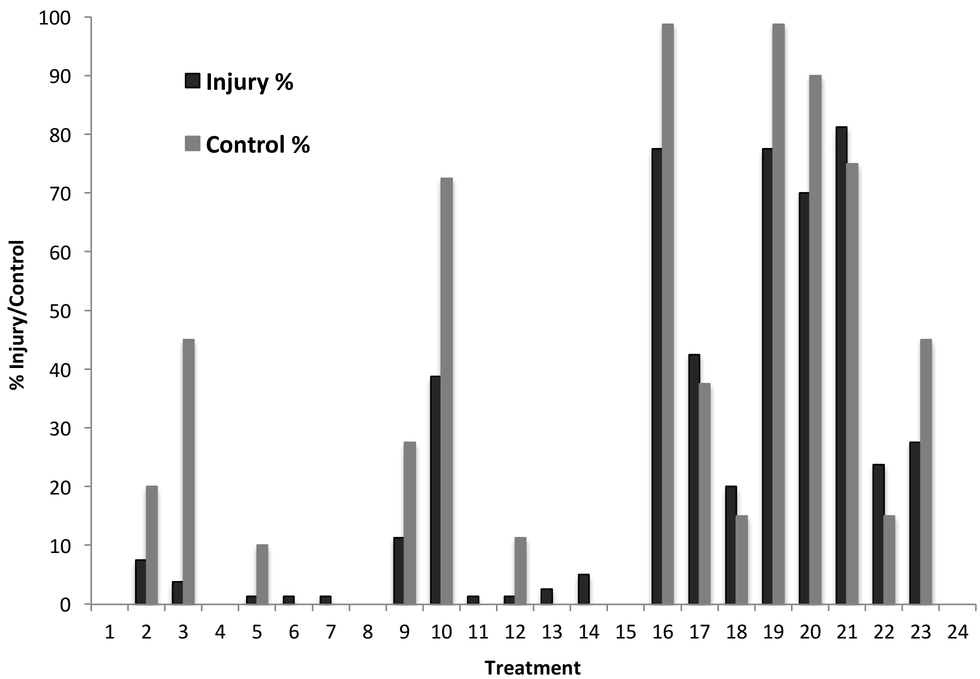

Figure 1. Percent crop injury and percent control (row persistence) in each treatment evaluated on May 30, 2016. Treatments 1 and 24 are control plots, 2 to 8 are early application, 9 to 15 are mid application, and 16 to 23 are late application.

Conclusions and Next Steps

Early applications of Goal (Treatment 4) and Chateau (Treatment 8) stood out as treatments with higher yields, but they did not yield significantly higher than the control plots. The late application timing (May 18) was too late, and spray timings will be made earlier in 2017. Based on the first year of data, there is no yield benefit to row spraying in second-year white clover fields, especially with the added cost and time of an additional field spray.

The trial will be repeated in the late winter/early spring of 2017.

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Table 2. Average flower head density measured on July 17, 2016 with 24 row-spraying treatments in a second-year white clover seed field. Ranked from highest to lowest number of flower heads/ft^2.

Treatment	Herbicide	Timing	Flower density[1]
			(heads/ft^2)
4	Goal	Early	36 a
18	Goal	Late	36 a
8	Chateau	Early	35 a
10	Express	Mid	33 ab
11	Goal	Mid	32 abc
15	Chateau	Mid	32 abc
14	Sharpen broadcast	Mid	32 abc
1	Control	—	31 abc
12	Rely	Mid	31 abc
7	Sharpen broadcast	Early	31 abc
13	Sharpen	Mid	31 abc
22	Chateau	Late	31 abc
24	Control	—	31 abc
23	Aim[2]	Late	30 abcd
6	Sharpen	Early	30 abcd
5	Rely	Early	29 abcd
3	Express	Early	29 abcd
2	Alion + Rely	Early	28 bcd
9	Alion + Rely	Mid	26 cd
20	Sharpen	Late	23 de
21	Sharpen broadcast	Late	18 ef
19	Rely	Late	13 fg
16	Alion + Rely	Late	10 g
17	Express	Late	2 h
LSD (P = 0.05)			6.7

[1]Means followed by the same letter are not significantly different at LSD (P = 0.05).

[2]Aim was used as a row-spray treatment only at the late timing because there was an extra plot.

Table 3. Average white clover seed yield with 24 row-spraying treatments in a second-year white clover seed field. Ranked from highest to lowest yield (lb/a). Yields were very low due to equipment challenges during harvest and are not representative of typical yields in the Willamette Valley.

Treatment	Herbicide	Timing	Seed yield[1]
			(lb/a)
8	Chateau	Early	186 a
24	Control	—	160 ab
1	Control	—	148 abc
4	Goal	Early	147 abc
15	Chateau	Mid	121 abcd
13	Sharpen	Mid	120 abcd
6	Sharpen	Early	112 bcde
11	Goal	Mid	107 bcde
9	Alion + Rely	Mid	105 bcde
12	Rely	Mid	102 bcde
22	Chateau	Late	98 bcde
18	Goal	Late	92 bcde
14	Sharpen broadcast	Mid	84 cde
7	Sharpen broadcast	Early	75 def
5	Rely	Early	71 defg
3	Express	Early	67 defgh
2	Alion + Rely	Early	58 defgh
10	Express	Mid	54 defgh
23	Aim[2]	Late	44 efgh
21	Sharpen broadcast	Late	10 fgh
20	Sharpen	Late	6 gh
16	Alion + Rely	Late	0 h
17	Express	Late	0 h
19	Rely	Late	0 h
LSD (P = 0.05)			69

[1]Means followed by the same letter are not significantly different at LSD (P = 0.05).
[2]Aim was used as a row-spray treatment only at the late timing because there was an extra plot.

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