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PEST SLUGS IN WESTERN OREGON SEED CROPS: STAKEHOLDER KNOWLEDGE, BAITING STRATEGIES, AND ATTITUDE TOWARD NOVEL MANAGEMENT TOOLS

R.J. McDonnell and N.P. Anderson

Introduction

Slugs are among the most damaging pests of agricultural production in western Oregon. A diverse range of crops are damaged by these invertebrates (Godan, 1983; Barker, 2002), particularly in the agriculture-rich Willamette Valley. Seed crops, including grasses, clovers, and radishes, are particularly vulnerable. For example, in recent years, slug damage has accounted for nearly $100 million in damage to the $500 million grass seed industry alone. Despite the economic losses caused by these organisms, control measures are focused heavily on the use of chemical molluscicides. However, considerable variation in efficacy of the most widely used active ingredients (metaldehyde, iron phosphate, and iron EDTA) is frequently reported by growers. During times of the year when slug populations are high, slug baits can no longer be relied on to provide effective control. Furthermore, other traditional slug management strategies now have limited use in Oregon. For example, in the early 2000s, the practice of burning crop residue after seed harvest was phased out in the Willamette Valley, and straw residue provides ideal microhabitat for slugs. Additionally, some seed producers have adopted no-till production for soil conservation purposes, and this change in cultivation practice has increased slug populations.

To gain insight into stakeholder knowledge of pest slug identification, current slug baiting strategies, and grower willingness to use potential novel approaches, such as biological control, we conducted a survey of more than 200 seed growers and other stakeholders (e.g., crop consultants) throughout the Willamette Valley. The ultimate goals were to identify topics for statewide grower training programs and educational events and to identify limitations with the current utilization of molluscicides by growers.

Methods

Live surveys using TurningPoint clickers were conducted during the winter OSU Extension seed crop and cereal production meetings held in Albany, Salem, and Forest Grove, OR, on January 9–10, 2018. Participating growers (more than 200) answered 16 multiple-choice questions (see Appendix) related to their slug identification knowledge, control methods, and willingness to use novel tools. For the purpose of this report, the results from the three survey locations are pooled together.

Results and Discussion

<u>Grower knowledge of pest slug identification</u>

Three of the most damaging slugs of seed and cereal crops grown throughout the Willamette Valley are the gray field slug (*Deroceras reticulatum*), the white-soled slug (*Arion circumscriptus*), and the marsh slug (*Deroceras laeve*). When polled, 46.4% of growers answered that they could identify one or two pest slug species that they commonly encounter in their production system. When tested using photographs of each species, 33.3% and 52.1% of growers correctly identified the marsh and white-soled slugs, respectively. However, to our surprise, only 10.8% of attendees correctly identified the gray field slug, which is the most damaging pest slug in the Valley. These data suggest that grower training in slug identification is urgently needed.

<u>Current slug control strategies</u>

Growers consider slugs as serious pests of their seed crops, with 92.2% of those surveyed answering that slugs are among the top five pests, 69.7% stating that they are among the top three pests, and 17% stating that they are the top pest in their production system. Also, according to 80.2% of stakeholders, slug pressure has increased on their farm over the past 20 years. In terms of slug baits, which are the mainstay of pest slug control throughout the Willamette Valley, only 29.5% were satisfied (27.6%) or very satisfied (1.9%) with their performance. This demonstrates that most users are neutral or unsatisfied with these management tools. Of the active ingredients available, metaldehyde is clearly preferred (86%) over iron phosphate (6.5%) and chelated iron (7.5%). In terms of metaldehyde formulations other than pelletized baits, only 24.2% of growers utilize liquid metaldehyde, 28.3% use the granular form, 20.1% use both formulations, and 27.4% use neither.

In established clover and grass seed fields, the majority of stakeholders (80.1%) on average have applied one or two applications of slug bait per year over the past

10 years. In seedling clover or grass seed fields, 48.3% and 42.6% of growers have applied one or two and three or four applications annually, respectively. As expected, this suggests that slug pressure is most damaging in seedling fields, compared to established crop fields, and that protecting the emerging crop from slugs is critical for yields. In terms of broadcasting rate, most growers (55.6%) apply 6–10 lb/acre, with 15.4% and 22.4% of growers applying less than 5 lb/acre and 11–15 lb/acre, respectively. Only 6.5% of growers apply more than 15 lb/acre. This indicates that growers prefer to apply multiple applications of bait at less than the label rate as opposed to a higher rate in a single application. Lastly, the majority of stakeholders (76.9%) surprisingly do not apply bait in the spring when the bulk of eggs are being laid by adult slugs.

Novel slug control tools

If novel slug control tools were available to stakeholders, 80.5% of those surveyed would use them if they were the same price as current methods, while 18.1% would wait for others to try first. If these tools were more expensive but gave more reliable control, 68% would use them and 31.1% would wait for others to try them first. In terms of cost, only 14.8% of growers would not pay more for these novel products, while 46.3% would pay 1.5 times as much, and 31% would pay twice as much. A small number of those surveyed would be willing to pay three times (4.4%) and up to five times (3.5%) as much. These data demonstrate the need and stakeholder desire for new strategies such as biological control for slug management in seed and cereal crops throughout the Willamette Valley.

Conclusions

The data collected through these surveys suggest that stakeholder training in slug identification is needed in the Willamette Valley. It is critically important that growers be able to identify different pest slugs in crops because different slug control tools have different efficacies against different pest species. For example, *Deroceras* slugs are more susceptible to metaldehyde than *Arion* slugs (Wedgewood and Bailey, 1988). Also, the use of liquid metaldehyde and the use of spring baiting by growers was lower than expected. Therefore, over the coming years we will try to determine the reasons for this low utilization and at the same time assess the impact of spring baiting (using a variety of active ingredients and formulations) on slug populations in the fall.

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Appendix. Multiple-choice questions used to survey seed crop and cereal stakeholders. The total number of growers and percentage of growers selecting a specific answer are provided for each question below.

1. How confident are you that you can correctly identify different pest slugs in your crops?

Only know it's a slug	46.38%	96
Know 1 or 2 species	46.38%	96
Know 3–5 species	6.28%	13
Know >5 species	0.97%	2

2. What is this slug? Asterisk denotes correct answer

Gray field slug*	10.81%	16
White-soled slug	8.11%	12
Leopard slug	62.16%	92
Banana slug	18.92%	28

3. What is this slug? Asterisk denotes correct answer

White-soled slug	53.74%	79
Marsh slug*	33.33%	49
Banana slug	7.48%	11
Leopard slug	5.44%	8

4. What is this slug? Asterisk denotes correct answer

Banana slug	13.82%	30
Leopard slug	15.67%	34
White-soled slug*	52.07%	113
Dusky slug	18.43%	40

5. In your opinion has slug pressure increased on your farm over the past 20 years?

Yes	80.28%	175
No	8.72%	19
I don't know	11.01%	24

6. Which of these slug baits do you use most often?

Metaldehyde, e.g., Deadline	85.98%	184
Iron phosphate, e.g., Sluggo	6.54%	14
Chelated iron, e.g., IronFist, Ferroxx	7.48%	16

7. In addition to metaldehyde pellets do you use the following formulations?

Granular, e.g., Durham	28.31%	62
Liquid, e.g., SlugFest	24.20%	53
Both	20.09%	44
Neither	27.40%	60

8. How many lb/acre of slug bait do you typically use per application?

0–5 lb/acre	15.42%	33
6–10 lb/acre	55.61%	119
11–15 lb/acre	22.43%	48
16–20 lb/acre	5.61%	12
>20 lb/acre	0.93%	2

9. How satisfied are you with the performance of slug baits?

Very unsatisfied	4.67%	10
Unsatisfied	22.90%	49
Neither satisfied nor unsatisfied	42.99%	92
Satisfied	27.57%	59
Very satisfied	1.87%	4

10. Over the past ten years, on average how many applications of slug bait do you make per year in an established clover or grass seed field?

1–2 applications	80.09%	169
3–4 applications	16.59%	35
5–6 applications	3.32%	7
>7 applications	0.00%	0

11. Over the past ten years, on average how many applications of slug bait do you make per year in a seedling clover or grass seed field?

1–2 applications	48.33%	101
3–4 applications	42.58%	89
5–6 applications	7.18%	15
>7 applications	1.91%	4

12. Do you regularly apply slug bait in the spring to your grass and clover fields?

Yes	23.15%	50
No	76.85%	166

13. Considering overall costs and damage, how would you rank slugs as a pest?

The worst	16.97%	37
Second worst	33.03%	72
Third worst	19.72%	43
Top 5	22.48%	49
Top 10	5.50%	12
Not top 10	2.29%	5

14. If novel tools such as biocontrol were available for slugs, how likely are you to use them if they were the same price as current methods?

I would try	80.47%	173
I would wait for others to try first	18.14%	39
I would not try	1.40%	3

15. If these novel tools were more expensive but gave more reliable control, how likely are you to use them?

I would try	67.94%	142
I would wait for others to try first	31.10%	65
I would not try	0.96%	2

16. If these tools consistently controlled slugs, how much extra would you be willing to pay?

Would not pay more	14.78%	30
1.5 times as much	46.31%	94
Twice as much	31.03%	63
Three times as much	4.43%	9
Five times as much	3.45%	7

WEED MANAGEMENT IN CARBON-SEEDED TALL FESCUE AND PERENNIAL RYEGRASS WITH PREEMERGENCE HERBICIDES

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

Introduction

Evaluation of herbicides for potential use with carbon seeding in the establishment of fall-seeded perennial ryegrass and tall fescue remains a priority in grass seed weed management in Oregon. Pyroxasulfone premixed with flumioxazin (Fierce) is in the registration process for use on grasses grown for seed and has performed well for management of diuron-resistant populations of annual bluegrass (*Poa annua*) in both new plantings with carbon seeding and in established stands. Indaziflam (Alion) also has performed well in carbon-seeding studies in perennial ryegrass and tall fescue (Curtis et al., 2011, 2012). The manufacturer of indaziflam has shown interest in the use of this product in grasses grown for seed.

Two studies were conducted during the 2016–2017 growing season in tall fescue and perennial ryegrass grown for seed to further evaluate crop safety and control of diuron-resistant annual bluegrass and roughstalk bluegrass (*Poa trivialis*) following applications of preemergent herbicides.

Table 1. Application and soil data, tall fescue.

Planting date	Sep. 27, 2016	—
Application date	Sep. 29, 2016	Nov. 17, 2016
Crop growth stage	Preemergence	4 leaf + 1 tiller
Poa annua growth stage	Preemergence	1–2 tillers
Poa trivialis growth stage	Preemergence	1–2 tillers
Air temperature (°F)	69	46
Relative humidity (%)	55	86
Wind (mph, direction)	0–1, NE	2, E
Cloud cover (%)	40	80
First moisture (inches)	Oct.1 (0.12)	Nov. 18 (0.02)
Soil temperature at 2 inches (°F)	70	46
Soil pH	5.7	—
Soil OM (%)	4.0	—
Soil CEC (meq/100g)	8.1	—
Soil texture	Silt loam	—

Table 2. Application and soil data, perennial ryegrass.

Planting date	Oct. 3, 2016	—
Application date	Oct. 4, 2016	Nov. 29, 2016
Crop growth stage	Preemergence	5 leaf + 1 tiller
Poa annua growth stage	Preemergence	1–2 tillers
Poa trivialis growth stage	Preemergence	1–2 tillers
Air temperature (°F)	61	52
Relative humidity (%)	78	57
Wind (mph, direction)	0–4, S	2, E
Cloud cover (%)	90	70
First moisture (inches)	Oct. 4 (0.11)	Nov. 29 (0.12)
Soil temperature at 2 inches (°F)	60	50
Soil pH	5.7	—
Soil OM (%)	4.0	—
Soil CEC (meq/100g)	8.1	—
Soil texture	Silt loam	—

Materials and Methods

'Falcon IV' tall fescue was planted in 18-inch rows on September 27, 2016, and 'APR 2190' perennial ryegrass was planted in 12-inch rows on October 3, 2016, at Hyslop Research Farm near Corvallis, OR. Seeds for both species were planted approximately 0.25 inch deep with a 1-inch-wide band of activated carbon (300 lb/acre) sprayed over the seed rows. Experimental design in both studies was a randomized complete block with four replications. Plots were 8 feet x 35 feet, with 15 rows of tall fescue or 24 rows of perennial ryegrass, both carbon seeded. Each plot had two rows of diuron-resistant *P. annua* grower screenings, two rows of *P. annua* grower screenings of unknown susceptibility, and two rows of grower screenings of *P. trivialis* planted without carbon in a fallow area in the front of each plot. Seedbed preparation included use of a roller to compact the surface to help obtain shallow, uniform seed placement. A small-plot, single-wheeled sprayer with output of 20 gpa at 20 psi was used to apply the herbicide treatments on September 29 and November 17 on the tall fescue and on October 4 and November 29 on the perennial ryegrass (Tables 1 and 2).

The studies, each consisting of ten herbicide treatments, included a grower standard of diuron + pronamide followed by ethofumesate and an untreated check (Tables 3 and 4). Treatments with glufosinate +

ethofumesate and glufosinate + oxyfluorfen were included to evaluate safety of treatments to remove weed species within the carbon-treated band. Plots were evaluated visually for crop injury and percent control of the *Poa* species. The tall fescue crop was swathed on June 27 and threshed with a small-plot combine on July 18. The perennial ryegrass was swathed on July 7 and threshed on July 19. Seed was cleaned with a Clipper Cleaner, and yields were quantified (Tables 3 and 4). Results were analyzed using ANOVA and means separated by LSD at 0.05.

Results and Discussion

The study site received 0.63 inch of rain between the herbicide application to the tall fescue and the planting of the perennial ryegrass. On the day of the herbicide application to the perennial ryegrass, the site received 0.11 inch of rain. During the following week, 1.46 inches of precipitation accumulated. During the week of grass seed emergence (tall fescue typically emerges in 10–14 days and perennial ryegrass in 7–10 days), rainfall was 5.7 inches. It takes approximately 4 inches of rainfall to dissipate a carbon band (Nortron SC label); thus, carbon protection was diminishing rapidly during seedling emergence. The heavy rainfall, combined with field preparation, led to standing water on the surface at plant emergence and for several days thereafter. October rainfall at the study site was 12.15 inches, which was the most ever recorded at Hyslop Research Farm. The 20-year October rainfall average for the site is 3.17 inches.

Seed yields for the tall fescue were very low, as planting was not early enough for adequate vernalization (Table 3).

In perennial ryegrass, clean seed yields with the lower rate of pyroxasulfone/flumioxazin, including treatments followed by glufosinate + ethofumesate, were equivalent to the untreated check and the grower standard treatment (Table 4). Severe crop injury (60% or greater) was observed in all of the indaziflam treatments and with the high rate of pyroxasulfone/flumioxazin (Table 4). This injury resulted in clean seed yield decreases. Extreme rainfall amounts during seed germination allowed the herbicide to move into the

Table 3. Control of two populations of *Poa annua* and *Poa trivialis*, crop injury, and seed yield with herbicide treatments in carbon-seeded tall fescue.

		Control[1]				
Treatment[2]	Rate	*Poa annua*	DR *Poa annua*[3]	*Poa trivialis*	Crop injury[1]	Clean seed yield
	(lb ai/a)	-------------------- (%)	--------------------	--------------------	(%)	(lb/a)
Untreated check	0	0	0	0	0	181
Pyroxasulfone/flumioxazin	0.07	96	92	94	4	160
Pyroxasulfone/flumioxazin	0.14	100	100	99	23	91
Indaziflam	0.01	100	100	100	50	83
Indaziflam	0.03	100	100	100	65	52
Pyroxasulfone/flumioxazin fb glufosinate + ethofumesate	0.07 0.18 + 1.0	100	98	100	11	167
Pyroxasulfone/flumioxazin fb glufosinate + oxyfluorfen	0.07 0.18 + 0.02	100	98	99	9	152
Indaziflam fb glufosinate + ethofumesate	0.01 0.18 + 1.0	100	100	100	21	144
Indaziflam fb glufosinate + oxyfluorfen	0.01 0.18 + 0.02	100	100	100	29	99
diuron + pronamide fb ethofumesate	1.6 + 0.25 1.0	98	83	99	0	253
LSD (*P* = 0.05)		3	4	2	13	106
CV		2	4	1	43	53

[1]Control and crop injury evaluated May 15, 2017.
[2]fb = followed by
[3]DR = diuron-resistant

seed row and inhibit root growth, thus preventing plant establishment. There is a risk of severe crop injury with the practice of carbon planting in wetter than normal years, especially in areas with poor drainage.

Control of the *Poa* species with all herbicide treatments was 89–100%, with the exception of the diuron + pronamide treatment with the diuron-resistant *P. annua* in the tall fescue trial (Tables 3 and 4). The application to tall fescue was made to dry soil, and more herbicide may have been tied to soil particles than in the perennial ryegrass, where the application was to moist soil.

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Table 4. Control of two populations of *Poa annua* and *Poa trivialis*, crop injury, and seed yield with herbicide treatments in carbon-seeded perennial ryegrass.

		Control[1]				
Treatment[2]	Rate	*Poa annua*	DR *Poa annua*[3]	*Poa trivialis*	Crop injury[1]	Clean seed yield
	(lb ai/a)	(%)	(%)	(%)	(%)	(lb/a)
Untreated check	0	0	0	0	0	1,091
Pyroxasulfone/flumioxazin	0.07	96	99	98	26	1,296
Pyroxasulfone/flumioxazin	0.14	100	100	100	78	472
Indaziflam	0.01	99	100	100	60	533
Indaziflam	0.03	100	100	100	93	26
Pyroxasulfone/flumioxazin fb glufosinate + ethofumesate	0.07 0.18 + 1	100	100	98	41	1,126
Pyroxasulfone/flumioxazin fb glufosinate + oxyfluorfen	0.07 0.18 + 0.02	100	100	100	40	1,209
Indaziflam fb glufosinate + ethofumesate	0.01 0.18 + 1.0	100	100	100	63	516
Indaziflam fb glufosinate + oxyfluorfen	0.01 0.18 + 0.02	99	100	100	75	451
Diuron + pronamide fb ethofumesate	1.6 + 0.25 1.0	89	90	95	5	1,244
LSD ($P = 0.05$)		4	4	3	24	228
CV		3	3	3	175	20

[1]Control and crop injury evaluated May 15, 2017.
[2]fb = followed by
[3]DR = diuron-resistant

SEQUENTIAL HERBICIDE APPLICATIONS FOR DOWNY BROME (*BROMUS TECTORUM*) CONTROL IN ESTABLISHED KENTUCKY BLUEGRASS FOLLOWING LATE-SEASON PROPANE FLAMING IN THE GRANDE RONDE VALLEY OF NORTHEASTERN OREGON

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

Introduction

A study was conducted during the fall of 2016 and spring of 2017 to evaluate downy brome (*Bromus tectorum*, BROTE) control and crop injury potential from sequential applications of preemergent and postemergent herbicides in established Kentucky bluegrass (KBG). Most herbicide products included in this trial are currently registered for use, except as follows:

- Flumioxazin + pyroxasulfon (Fierce), indaziflam (Alion), and topramezone (Impact) are not registered for use in any grass seed crops in the Pacific Northwest.
- Metribuzin products are not registered for use in northeastern Oregon or Columbia Basin grass seed production.
- East of the Cascades, flucarbazone (Everest) is registered only for Kentucky bluegrass seed crops during the establishment year.

Materials and Methods

The experiment was located in an established commercial field of 'Merit' Kentucky bluegrass in the Grande Ronde Valley (GRV) of northeastern Oregon. Plots were 8 feet x 25 feet and arranged in a randomized complete block design with four replications. Soil at the site is a Palouse silt loam (37.6% sand, 52.0% silt, 10.4% clay), with 4.75% organic matter (OM), pH of 4.6, and cation exchange capacity (CEC) of 29.2 meq/100g).

The field was seeded during spring of 2014, and the third seed crop was harvested in July 2017. After baling the crop residue, the field was propane flamed on September 2, 2016, harrowed twice, and then reflamed. Starter fertilizer was applied on September 9, 2016. Pendimethalin (Prowl H2O) was applied at 5 pt/acre by the grower on September 10. Approximately 4 inches of irrigation water was applied with a wheel line sprinkler system following this preemergent (PRE) herbicide application.

Early postemergent (EPOST) herbicide treatments were applied on September 25, 2016 to emerging BROTE with coleoptiles 1 inch or less in height. Mid-postemergent (MPOST) treatments were applied on October 22, 2016. Late postemergent treatments were applied on November 13, 2016. Environmental conditions at the time of herbicide application are summarized in Table 1. Sequential treatment information and site of action descriptions for each active ingredient are listed in Tables 2 and 3 (respectively). 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.

Seed yield was not determined in this study. The trial site was mowed in late May 2017 due to crop destruct requirements of using nonregistered herbicides.

Table 1. Environmental conditions at time of herbicide application.

Application date	Sept. 25, 2016	Oct. 22, 2016	Nov. 13, 2016
Application timing	Early post (EPOST)	Mid-post (MPOST)	Late post (LPOST)
KBG growth stage	0–4 inches regrowth	4–6 inches	4–6 inches
BROTE growth stage	Coleoptile, 1 inch	3 inches, 2–4 tillers	4 inches, 3–5 tillers
Air temperature (°F)	72	53	48
Relative humidity (%)	33	47	85
Cloud cover	Clear and sunny	Partly cloudy	100% overcast
Wind velocity (mph)	0–3 from SSW	0–4 from NNE	0–2 from NNE
Soil temperature, surface (°F)	72	54	49
Soil temperature, 1 inch (°F)	80	55	48
Soil temperature, 2 inch (°F)	74	54	49
Soil temperature, 4 inch (°F)	61	54	48

Results and Discussion

The late fall of 2016 in the GRV was wet due to significant rainfall events beginning in late September and continuing until December (Figure 1). Early-fall conditions were drier except for a few rainfall events, which resulted in 0.39 inch of rainfall (IMBO AgriMet) between July 15, 2016 and September 10, 2016. The trial site received approximately 0.22 inch of rainfall between the PRE and EPOST herbicide applications, which promoted BROTE germination and emergence. BROTE emergence began September 10–25. An additional 1.48 inches of rainfall was received between application of EPOST and MPOST treatments. BROTE had developed two to five tillers by mid-November.

Visual evaluations of BROTE control were taken on November 13, 2016; March 16, 2017; and May 4, 2017 (Figure 2). The trial site was heavily infested with a uniformly distributed BROTE population. Acceptable levels of BROTE control (75–79%) were documented

Table 2. Sequential herbicide applications for downy brome (BROTE) control in established Kentucky bluegrass in the Grande Ronde Valley of northeastern Oregon, 2017 (Exp. 17-102).

Treatment	Treatment[1]	Active ingredient	Rate	Application timing	Site of action
			(per acre)		(group #)
1	Untreated check				
2	Outlook	Dimethenamid-p	21 fl oz	EPOST	15
3	Goal 2XL	Oxyfluorfen	8 oz	EPOST	14
	+ metribuzin DF	Metribuzin	2.7 oz		5
4	Beacon	Primisulfuron	0.38 oz	EPOST	2
	+ Sinbar WDG	Terbacil	0.5 lb		5
5	Callisto	Mesotrione	6 fl oz	EPOST	27
	+ Sinbar WDG	Terbacil	0.5 lb		5
6	Beacon fb	Primisulfuron	0.38 oz	EPOST	2
	Beacon	Primisulfuron	0.38 oz	MPOST	2
	+ Sinbar WDG	Terbacil	0.5 lb		5
7	Goal 2XL	Oxyfluorfen	8 fl oz	MPOST	14
	+ Sinbar WDG	Terbacil	0.5 lb		5
8	Goal 2XL	Oxyfluorfen	8 fl oz	EPOST	14
	+ Everest	Flucarbazone	1 fl oz		2
9	Beacon fb	Primisulfuron	0.76 oz	EPOST	2
	Outlook	Dimethenamid-p	21 fl oz	MPOST	15
10	Goal 2XL	Oxyfluorfen	8 fl oz	EPOST	14
	+ metribuzin DF fb	Metribuzin	2.7 oz		5
	Beacon	Primisulfuron	0.38 oz	MPOST	2
	+ Sinbar	Terbacil	0.5 lb		5
11	Beacon fb	Primisulfuron	0.38 oz	EPOST	2
	Beacon	Primisulfuron	0.38 oz	MPOST	2
	+ Sinbar WDG fb	Terbacil	0.5 lb		5
	Prowl H2O	Pendimethalin	5 pt	LPOST	3
12	Goal 2XL	Oxyfluorfen	8 fl oz	EPOST	1
	+ Sinbar fb	Terbacil	0.5 lb		5
	Outlook	Dimethenamid-p	21 fl oz	LPOST	15
13	Fierce	Flumioxazin + pyroxasulfon	3 oz	MPOST	14 +15
	+ Goal 2XL	Oxyfluorfen	2 fl oz		14
			0.25% v/v		
14	Alion	Indaziflam	2 fl oz	MPOST	29
	+ Goal 2XL	Oxyfluorfen	3 fl oz		14
			1% v/v		
15	Impact	Topramezone	2 fl oz	MPOST	27

[1]fb = followed by

Table 3. Site of action descriptions for herbicides included in the 2016–2017 downy brome trial.

Group #	Description (Weed Science Society of America)
2	Inhibits ALS (branched chain amino acid synthesis/cell division in roots and shoots)
3	Inhibits microtubule assembly (cell division in roots and shoots); swelling of root tips
5	Inhibits photosystem II (photosynthesis); loss of chlorophyll and carotenoids; leaky cells
14	Inhibits protoporphyrinogen oxidase (PPO); loss of chlorophyll; leaky cell membranes
15	Inhibits synthesis of very long chain fatty acids (VLCFA); affects seedling emergence
27	Inhibits 4-HPPD enzyme for carotenoid synthesis; bleaches new tissues
29	Inhibits cellulose synthesis

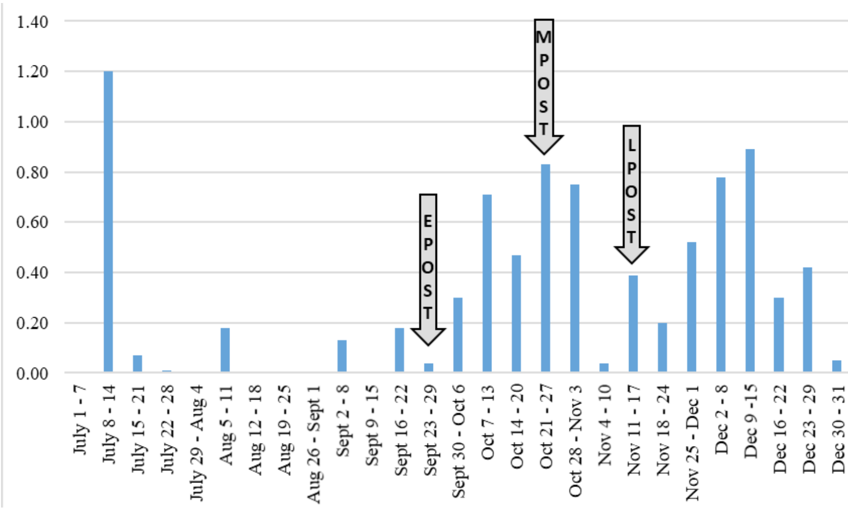

Figure 1. Weekly precipitation (inches) at Imbler AgriMet station (IMBO), fall 2016.

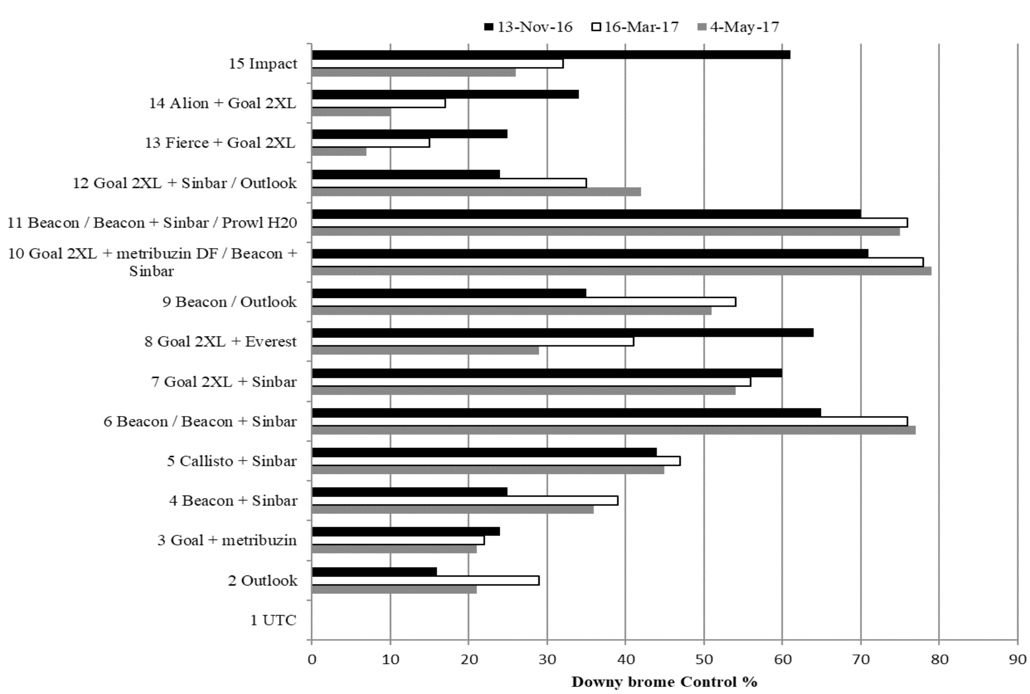

Figure 2. Downy brome control from sequential herbicide application in established Kentucky bluegrass in the Grande Ronde Valley of northeastern Oregon, fall 2016 and spring 2017.

from three sequential treatment combinations (Treatments 6, 10, and 11) following the PRE application of Prowl H2O (Figure 2). Treatments 6 and 11 included split application of Beacon (0.38 oz/acre) applied EPOST, followed by Beacon (0.38 oz/acre) + Sinbar (0.5 lb/acre) applied MPOST. Adding an LPOST application of Prowl H2O (5 pt/acre) did not appear to improve BROTE control (Treatment 11). Goal 2XL + metribuzin applied EPOST followed by Beacon + Sinbar (Treatment 10) resulted in slightly better BROTE control compared to Treatments 6 and 11, but slight crop injury (2%) was observed on May 4, 2017. No other treatments showed symptoms of crop injury in May 2017; however, most treatments did result in slight crop injury in November 2016 (Figure 3). Fierce, Alion, and Impact treatments did not provide adequate BROTE control (Figure 2). Product evaluations are for experimental purposes only; therefore, mention of the products used in this trial is not to be considered a recommendation for commercial use.

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Acknowledgments

A special thanks to the Union County Seed Growers Association, Glenn Farms, and M&M Farms for their contributions to this project.

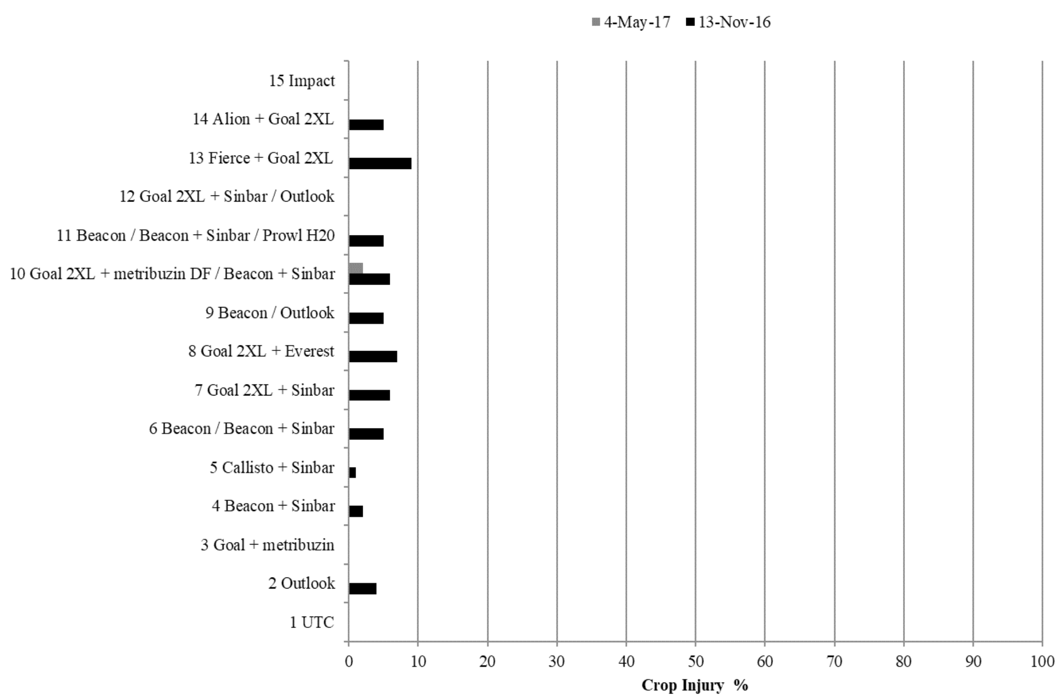

Figure 3. Crop injury from sequential herbicide applications in established Kentucky bluegrass in the Grande Ronde Valley of northeastern Oregon, fall 2016 and spring 2017.

SPRING-APPLIED NITROGEN AND PLANT GROWTH REGULATOR EFFECTS ON ORCHARDGRASS SEED YIELD

N.P Anderson, T.G. Chastain, A.D. Moore, and C.J. Garbacik

Introduction

Forage grass seed crops, including orchardgrass (*Dactylis glomerata* L.), are a vital part of seed production enterprises in Oregon. Like other cool-season grasses, orchardgrass produces only a fraction of its potential seed yield. Lodging of the crop during flowering is one of the major factors limiting maximum seed yield. A recent decline in orchardgrass growers and acreage, coupled with relatively strong market demand, makes it important to maximize production on the remaining orchardgrass acreage. Making better use of nitrogen (N) and plant growth regulators (PGRs) is a way to achieve that objective.

Two stem-shortening PGRs, chlormequate chloride (CCC, trade name Cyclocel) and trinexapac-ethyl (TE, trade name Palisade EC), enhance seed yield in forage grasses by blocking gibberellic acid (GA) biosynthesis. Prior to the development of TE, CCC was used commercially in perennial ryegrass (*Lolium perenne* L.) seed crops in New Zealand, where it produced 34–44% seed yield increases (Hampton, 1986). The greater seed yield response to TE in comparison to CCC resulted in rapid grower adoption of TE globally. Recent studies in western Oregon have shown 46–62% reductions in lodging, a result of stem shortening, when TE was applied to tall fescue (*Schedonorus phoenix* [Scop.] Holub) crops at 1.5 pt/acre and 3 pt/acre, respectively (Chastain et al., 2015). In perennial ryegrass, seed yield increased 14 lb/acre for every 0.4-inch reduction in stem length (Chynoweth et al., 2014).

In comparison with tall fescue and perennial ryegrass, seed yield response to PGRs in orchardgrass is relatively understudied. Gingrich and Mellbye (2002) reported seed yield increases ranging between 6 and 19% when TE was applied at flag leaf to early head emergence. A recent study conducted by Rolston et al. (2014) in New Zealand indicated that orchardgrass seed yield increases of 30–37% are possible when TE is applied earlier, at the two-node stage. In this same study, a mixture of TE + CCC was more effective at increasing seed yield across four orchardgrass cultivars than either CCC or TE applied alone.

Although CCC and TE are both GA inhibitors, CCC acts in the early steps of GA biosynthesis, while TE acts late in the pathway. Combinations of PGRs that act at separate locations in the GA pathway may produce additive effects on seed yield. Positive outcomes have resulted from such combinations. For example, when a tank-mix of CCC and TE was applied to orchardgrass, seed yields increased by 84% across five New Zealand experiments (Rolston et al., 2014).

Since lodging is exacerbated in the high-nitrogen environments present in grass seed production systems, additional work is needed to determine possible interactions between PGRs and spring-applied N under western Oregon conditions. Recommendations for application rates of N fertilizer in orchardgrass have not been revised and have not appeared in the international seed production literature since PGRs were introduced in this important forage seed crop. In Oregon, OSU fertilizer recommendations for orchardgrass seed crops (Doerge et al., 2000) are more than 15 years old, and new information is needed to evaluate whether N rate recommendations should be adjusted to further increase seed yield in current management environments.

The objectives of this multiyear study were (1) to measure the effects of multiple N fertilizer rates in the presence and absence of TE and TE + CCC plant growth regulators and (2) to define optimum treatment and timing applications of TE and TE + CCC plant growth regulators for orchardgrass seed crops.

Materials and Methods

A field trial with ‘Persist’ orchardgrass was established in October, 2015 at OSU’s Hyslop Research Farm. Plot size is 11 feet x 38 feet. Fungicide and insecticide treatments were applied to manage pests as needed. Fall N was applied to all plots at a rate of 40 lb N/acre during 2015 and 2016. The first harvest year following the establishment period was 2017. The experimental design for the trial was a randomized complete block with a split-plot arrangement of treatments and three replications. Main plots received spring-applied N at rates of:

- 0 lb N/acre
- 100 lb N/acre
- 140 lb N/acre
- 180 lb N/acre

PGR subplots included the following treatments and application rates:

- Untreated control (No PGR)
- 1.5 pt/acre TE applied at BBCH 32 (2 nodes)
- 1.5 lb/acre TE applied at BBCH 51 (panicles 10% emerged)
- 0.75 pt/acre TE + 1.34 lb/acre CCC (2 nodes)

Spring N was applied on March 16, 2017 using a tractor-mounted orbit-air spreader system with appropriate amounts of 46-0-0. The PGR treatments were applied at the two-node stage (BBCH 32) and when panicles were 10% emerged (BBCH 51) using a bicycle-type boom sprayer operated at 20 psi delivering 20 gpa with XR Teejet 8003VS nozzles. Above-ground biomass samples were taken from each plot near crop maturity, and dry weight of the standing crop was determined. Total tissue N content was measured from the above-ground biomass samples. Tiller height was measured for each treatment at harvest maturity. Lodging ratings were determined just prior to swathing.

Seed was harvested by a small-plot swather and combine, and seed was cleaned to determine 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 (HI), the ratio of seed yield to above-ground biomass, was also quantified.

Results and Discussion

All treatments containing spring-applied N increased seed yield in orchardgrass, in comparison with the untreated control (Table 1). Maximum seed yield was attained with 100 lb N/acre, and there was no additional benefit from higher N rates. Nitrogen also increased seed number and biomass, but had no effect on percent cleanout, seed weight, fertile tiller number, or HI. Total tissue N concentration did not increase when rates above 100 lb/N acre were applied (data not shown); thus, it is not surprising that seed yield did not further increase with higher N rates. Spring-applied N had no effect on lodging in the first-year orchardgrass crop.

Seed yield was also significantly increased by PGR treatments (55%). However, there were no differences among PGR timings or between TE and the TE + CCC mixture (Table 2). All PGR treatments increased seed number and HI, but there were no effects on seed

Table 1. Effect of nitrogen (N) on seed yield, yield components, and growth characteristics of first-year orchardgrass.[1]

N treatment	Yield	Cleanout	Seed wt.	Seed no.	Biomass	Fertile tillers	Tiller height	Harvest index	Lodging
(lb/a)	(lb/a)	(%)	(mg/seed)	(seeds/m^2)	(kg/ha)	(no./ft^2)	(cm)	(%)	(%)
0	608 a	8.3 a	0.921 a	73,912 a	10,351 a	48.9 a	119 a	6.6 a	6.5 a
100	726 b	8.3 a	0.914 a	89,196 b	11,815 b	41.6 a	117 a	7.1 a	4.4 a
140	729 b	7.9 a	0.931 a	88,217 b	11,008 ab	41.4 a	116 a	7.6 a	4.7 a
180	796 b	8.4 a	0.921 a	96,934 b	13,323 c	44.0 a	115 a	6.8 a	5.9 a

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

Table 2. Effect of plant growth regulators (PGRs) on seed yield, yield components, and growth characteristics of first-year orchardgrass.[1]

PGR treatment	Yield	Cleanout	Seed wt.	Seed no.	Biomass	Fertile tillers	Tiller height	Harvest index	Lodging
	(lb/a)	(%)	(mg/seed)	(seeds/m^2)	(kg/ha)	(no/ft^2)	(cm)	(%)	(%)
Control (No PGR)	504 a	8.9 b	0.921 ab	61,402 a	11,624 a	43.7 a	133 c	4.8 a	13.7 c
Palisade 1.5 pt/a (BBCH 32)	785 b	7.8 a	0.929 b	94,922 bc	11,669 a	42.9 a	118 b	7.6 b	4.7 b
Palisade 1.5 pt/a (BBCH 51)	780 b	7.4 a	0.935 b	93,654 b	12,652 a	50.4 a	115 b	7.1 b	3.1 b
Palisade 0.75 pt/a + CCC 1.34 lb ai/a	790 b	8.6 b	0.902 a	98,282 c	10,552 a	38.9 a	100 a	8.6 c	0.0 a

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

weight, biomass, or fertile tiller number. Lodging was significantly reduced with PGRs, compared to the untreated control, and no lodging was observed in the TE + CCC mixture treatment. Reduction in lodging from PGRs was made possible by a reduction in tiller height.

An interaction of spring-applied N and PGR for seed yield was evident in this first-year study (Figure 1). The combination of spring-applied N and PGRs produced the greatest seed yields. One interesting finding is that, despite this positive interaction, seed yield was enhanced by PGRs even when no spring N was applied. In other grass seed crops, such as tall fescue and perennial ryegrass, increased seed yield from PGR applications have not been found when no spring N is applied.

The results of this first-year study indicate that applying a combination of spring-applied N and PGRs can increase orchardgrass seed yield in western Oregon conditions, even when lodging is minimal. This work will be repeated in 2018 to examine the effects of these treatments on a second-year stand.

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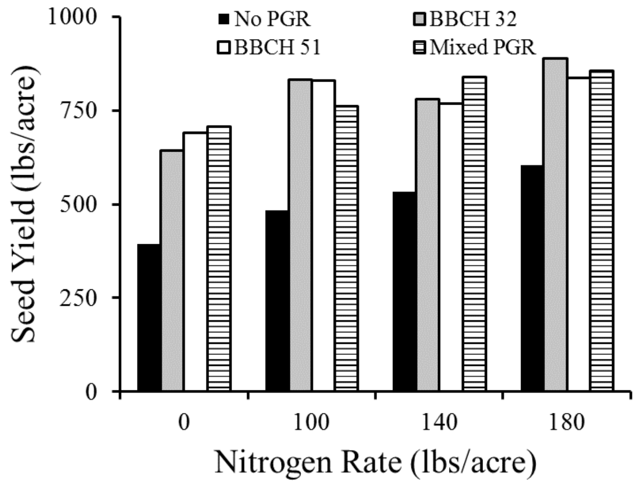

Figure 1. Interaction of spring-applied nitrogen (N) and plant growth regulators (PGRs) on seed yield in first-year orchardgrass.

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Acknowledgments

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EFFECTS OF PLANT GROWTH REGULATOR MIXTURES ON TURF-TYPE AND FORAGE-TYPE TALL FESCUE SEED CROPS

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

Introduction

Tall fescue is an important cool-season forage and turf grass and ranks among the most important seed crops in Oregon. Unfortunately, cool-season grasses produce only a fraction of their potential seed yield. Young et al. (1998) reported that tall fescue seed crops produced 37–53% of their potential yield, making them inefficient seed producers.

Use of trinexapac-ethyl (TE) plant growth regulator (PGR) in grasses grown for seed has been widely adopted in grass seed production around the globe. Chlormequat chloride (CCC) and paclobutrazol (PB) are not currently registered for use in grass seed crops in Oregon. All three PGRs inhibit gibberellic acid (GA) biosynthesis, each acting at different locations in the GA pathway. The PGRs fall into one of three categories of GA biosynthesis inhibitors: CCC is an onium-type compound, TE is a structural mimic of 2-oxoglutaric acid (acylcyclohexandione), and PB is a triazole with a nitrogen-containing heterocycle. Tall fescue seed yield was increased 40% over the untreated control with applications of TE to control lodging (Chastain et al., 2015). In New Zealand, combinations of TE, CCC, and PB increased seed yield by up to 95% in perennial ryegrass (Chynoweth et al., 2014) and up to 86% in orchardgrass (Rolston et al., 2014).

There has been no previous research conducted in Oregon to indicate whether a combination of PGRs will affect seed yield in tall fescue. In New Zealand, forage-type cultivars make up a majority of the perennial ryegrass and tall fescue seed crops, whereas in Oregon, tall fescue and perennial ryegrass seed crops consist mostly of turf-type cultivars.

The objectives of this study are: (1) to evaluate the effect of PGR combinations on lodging, above-ground biomass, plant height, and stem length in turf- and forage-type tall fescue cultivars, and (2) to determine the effect of PGR combinations on seed yield, seed weight, and seed number.

Materials and Methods

The study included ‘Fawn’ forage-type and ‘Spyder’ turf-type tall fescue and was conducted in field trials at the OSU Hyslop Farm near Corvallis, OR, in spring 2017. The study will be repeated in spring 2018 at the same study site. Soil type at the study site is a Woodburn silt loam. Study design is a randomized complete block with four replications. Plot size was 11 feet x 50 feet. Treatments evaluated include:

- Untreated control
- 1.5 pt/a TE
- 1.34 lb ai/a CCC
- 0.75 pt/a TE + 0.67 lb ai/a CCC
- 1.5 pt/a TE + 1.34 lb ai/a CCC
- 1.5 pt/a TE + 0.67 lb ai/a CCC
- 0.75 pt/a TE + 1.34 lb ai/a CCC
- 1.5 pt/a TE + 1.34 lb ai/a CCC + 0.45 lb ai/a PB

Nitrogen was applied in March as a split application, at a total rate of 135 kg N/ha. PGRs were applied at BBCH 32 (two-node stage) with a bicycle-type boom sprayer.

Biomass measurements were taken near peak anthesis (BBCH 65). Crop height, length of stems, and assessment of lodging were done during late anthesis (BBCH 69).

Harvest timing was determined based on seed moisture content. The seed crop was harvested with a small-plot swather, and seed was threshed with a small-plot combine after seed moisture content was reduced to approximately 12%. Seed yield was determined on cleaned seed, and seed number was calculated using seed yield and seed weight. Samples were taken from the harvested seeds and were cleaned by the use of screens and blowers. An electronic seed counter counted two 1,000-seed samples, which were used to determine seed weight.

Analysis of variance (ANOVA) was used to test PGR and PGR mixture effects on seed yield and other characteristics of tall fescue seed production, and Fisher’s protected least significant difference (FPLSD) values were used to separate treatment means.

Results and Discussion

Above-ground biomass production was not affected by any PGR treatment within either cultivar (data not shown). However, as expected, the forage-type cultivar produced 25% more biomass than the turf-type cultivar. Tiller height was reduced by TE alone but not by CCC alone in both ‘Spyder’ and ‘Fawn’ cultivars (data not shown). Mixtures of 1.5 pt/a TE + 1.34 lb ai/a CCC and TE + CCC + PB reduced tiller height more than TE alone in ‘Spyder’ (data not shown). Only the TE + CCC + PB mixture in ‘Fawn’ reduced tiller height over TE alone.

Both cultivars experienced lodging in spring 2017, beginning earlier in ‘Fawn’ than in ‘Spyder’. Applications of TE alone provided significant control of lodging in both cultivars, while CCC alone did not (Figures 1 and 2). Lodging of the plants in ‘Fawn’ had already begun prior to the first measurement. Mixtures with 0.75 pt/a TE were less effective in lodging control than mixtures with 1.5 pt/a TE. The mixture with TE + CCC + PB provided maximum lodging control throughout the period in both cultivars.

Seed yield response to PGRs and PGR mixtures varied between the forage-type and turf-type cultivar (Table 1). Application of PGRs affected seed yield of both cultivars, when compared with the untreated control. In ‘Fawn’, the highest seed yields were evident in all treatments that contained 1.5 pt/a TE. The CCC alone treatment did not produce increased seed yields over the untreated control. Increased seed yields in ‘Fawn’ from treatments containing TE ranged from 28 to 51% over the control. In the turf-type cultivar ‘Spyder’, the highest seed yield was observed in the 1.5 pt/a TE + 0.67 lb ai/a CCC mixture. This PGR treatment increased seed yield by 29% over the untreated control but was no different in yield from the 1.5 pt/a TE +1.34 lb ai/a CCC mixture. No other PGRs or mixtures improved yield over the untreated control. Seed yield loss in lots treated with TE + CCC + PB (18%) was significantly lower than in the control.

Yield responses in both cultivars can largely be attributed to the effects of PGR treatments on reduced lodging and resultant seed number increases from better pollination and seed set (Table 2). The largest increases in seed number were observed in ‘Fawn’ with the TE + CCC + PB mixture, 1.5 pt/a TE + 0.67 lb ai/a CCC mixture, and TE alone. These treatments also had high seed yields. In ‘Spyder’, the 1.5 pt/a TE + 0.67 lb ai/a CCC mixture and the 1.5 pt/a TE + 1.34 lb ai/a CCC mixture had both high seed number and seed yield. The TE + CCC + PB mixture did not increase seed number over the control, and this treatment had seed yields that were significantly lower than the control. The TE alone, CCC alone, 0.75 pt/a TE + 1.34 lb ai/a CCC mixture, and the 0.75 pt/a TE + 0.67 lb ai/a CCC mixture all had seed number that were not different from the control.

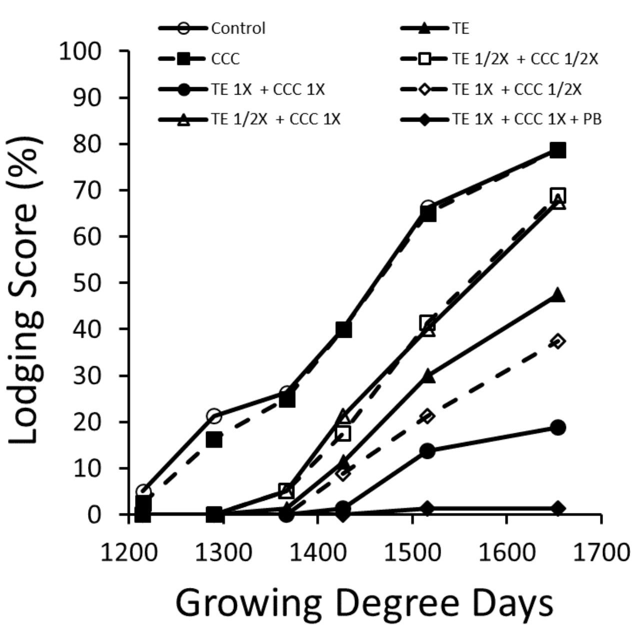

Figure 1. Effect of PGR and PGR mixtures on lodging in ‘Spyder’ turf-type tall fescue in spring 2017. TE 1X = 1.5 pt/a, TE 1/2X = 0.75 pt/a, CCC 1X = 1.34 lb ai/a, CCC 1/2X = 0.67 lb ai/a.

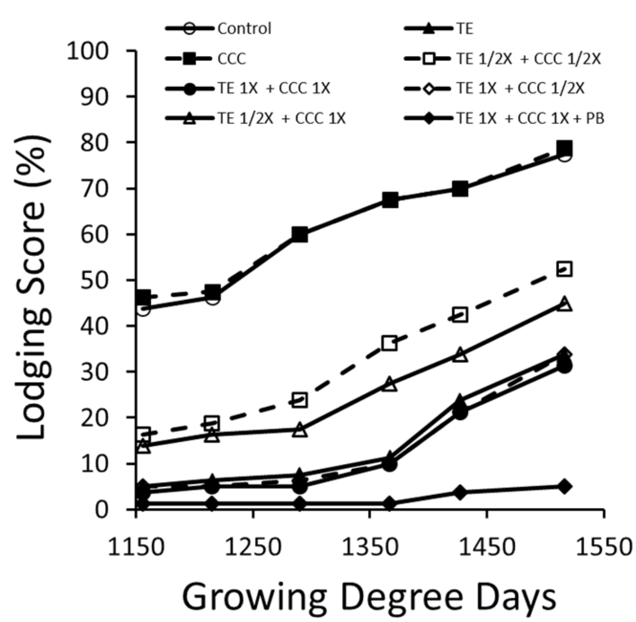

Figure 2. Effect of PGR and PGR mixtures on lodging in ‘Fawn’ forage-type tall fescue in spring 2017. TE 1X = 1.5 pt/a, TE 1/2X = 0.75 pt/a, CCC 1X = 1.34 lb ai/a, CCC 1/2X = 0.67 lb ai/a.

These treatments also produced seed yields equivalent to the control.

Seed weight was affected by PGR mixtures in 'Fawn' (Table 2). The 1.5 pt/a TE +1.34 lb ai/a CCC mixture increased seed weight over the control, whereas the TE + CCC + PB mixture reduced seed weight. Seed weight did not appear to have any effect on seed yields since the TE + CCC + PB mixture had low seed weight but also had high seed yield. There was no significant difference in seed weight among PGR treatments in 'Spyder'.

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Table 1. Seed yield response of 'Fawn' forage-type and 'Spyder' turf-type tall fescue cultivars to combinations of plant growth regulators (PGRs).

		Cultivar[1]	
PGR[2]	Rate	Fawn	Spyder
		(lb/a)	
Control	0	704 d	1,511 bc
TE	1.5 pt/a	1,011 ab	1,619 bc
CCC	1.34 lb ai/a	812 cd	1,532 bc
TE + CCC	0.75 pt/a + 0.67 lb ai/a	904 bc	1,603 bc
TE + CCC	1.5 pt/a + 1.34 lb ai/a	1,000 ab	1,781 ab
TE + CCC	1.5 pt/a + 0.67 lb ai/a	1,055 a	1,948 a
TE + CCC	0.75 pt/a + 1.34 lb ai/a	918 bc	1,416 cd
TE + CCC + PB	1.5 pt/a + 1.34 lb ai/a + 0.45 lb ai/a	1,063 a	1,235 d
LSD (*P* = 0.05)		45.22	16.95

[1]Means followed by the same letter are not different by Fisher's protected LSD values (*P* = 0.05).
[2]TE = trinexapac-ethyl; CCC = chlormequat chloride; PB = paclobutrazol.

Table 2. Seed number and seed weight response of 'Fawn' forage-type and 'Spyder' turf-type tall fescue cultivars to combinations of plant growth regulators (PGRs).

		Seed number[1]		Seed weight[1]	
PGR[2]	Rate	Fawn	Spyder	Fawn	Spyder
		(no/m^2)		(mg)	
Control	0	27,779 e	75,009 cd	2.85 b	2.27 a
TE	1.5 pt/a	40,186 abc	81,221 bc	2.83 b	2.24 a
CCC	1.34 lb ai/a	32,442 de	76,267 cd	2.81 b	2.26 a
TE + CCC	0.75 pt/a + 0.67 lb ai/a	35,139 cd	79,884 bc	2.89 b	2.25 a
TE + CCC	1.5 pt/a + 1.34 lb ai/a	38,007 bcd	92,743 ab	2.95 a	2.16 a
TE + CCC	1.5 pt/a + 0.67 lb ai/a	40,865 ab	98,230 a	2.90 ab	2.23 a
TE + CCC	0.75 pt/a + 1.34 lb ai/a	36,370 bcd	73,612 cd	2.84 b	2.16 a
TE + CCC + PB	1.5 pt/a + 1.34 lb ai/a + 0.45 lb ai/a	44,278 a	62,524 d	2.70 c	2.22 a
LSD (*P* = 0.05)		2,006	4,892	0.035	0.031

[1]Means followed by the same letter are not different by Fisher's protected LSD values (*P* = 0.05).
[2]TE = trinexapac-ethyl; CCC = chlormequat chloride; PB = paclobutrazol

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EXAMINING POSSIBLE BENEFITS OF PLANT GROWTH REGULATOR MIXTURES ON SECOND-YEAR TALL FESCUE SEED CROPS

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

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 37–53% of potential seed yield under Oregon conditions. Lodging of the crop during flowering and seed shattering are two primary factors limiting seed yield production. 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, a result of stem shortening, ranging from 46 to 62%, when TE was applied to tall fescue at 1.5 pt/acre and 3 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, whileTE acts late in the pathway.

The objective of this 2-year study was to investigate whether combinations of PGRs that act at different points in the GA pathway have additive effects on seed yield. Results from year 1 of this trial conducted by Anderson et al. (2017) on first-year tall fescue (turf-type) stands indicate that a single application of TE (1.5 pt/acre) increased seed yield by 24.9% across four trials, but there was no additional benefit of adding CCC to the PGR applications. The second year of this study aimed to evaluate whether there were differences between treatments in second-year stands.

Materials and Methods

In 2017, field trials were continued on four commercial second-year tall fescue (turf-type) seed fields, located across the Willamette Valley. Each field was spring planted in 2015, and PGR treatments were applied in the spring of 2016. The trial was reestablished in 2017 on the same footprint as the previous year. The experimental design for the trials was a randomized complete block with three replications. 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.

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

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 (HI), the ratio of seed yield to above-ground biomass, was also determined.

Results and Discussion

All treatments that contained TE reduced lodging in second-year tall fescue, in comparison with the untreated control (Table 1). The control treatment was moderately lodged (52%) across the trials. Reduction in lodging from TE alone was large (92%) 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.

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, except for Polk County, where treatments containing 1.5 pt/acre TE reduced biomass.

Seed yields were variable but were higher than the 10-year yield average. Application of TE consistently controlled lodging in tall fescue in all cultivars in these studies. There was a positive effect of TE and mixes of TE + CCC on seed yield at all locations, except at Linn County. The 1.5 pt/acre TE treatment increased seed yield by 17% across all four sites.

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 in these second-year stands. Seed weight changes were variable between treatments and sites, but there were no negative effects on seed weight from PGRs. 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 significantly affected by TE and/or TE + CCC mixture applications at two of the four sites (Table 2).

The results of the second year of this 2-year study indicate that adding CCC to TE applications can further reduce lodging but does not have any economic seed yield advantage in turf-type tall fescue 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	76.7 c	35.0 b	61.7 b	33.3 b
TE 1.5 pt/a	15.0 ab	0.0 a	15.0 a	3.3 a
CCC 1.34 lb ai/a	73.3 c	33.3 b	60.0 b	28.3 b
TE 1.5 pt/a + CCC 0.67 lb ai/a	15.0 ab	1.7 a	15.0 a	3.3 a
TE 1.5 pt/a + CCC 1.34 lb ai/a	10.0 a	0.0 a	15.0 a	0.0 a
TE 0.75 pt/a + CCC 0.67 lb ai/a	26.7 b	5.0 a	23.3 a	1.7 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	HI[2]
	------------------------------------ Washington County ------------------------------------					
	(lb/a)	(mg/seed)	(ton/a)	(cm)	(seeds/m²)	(%)
Untreated control	2,381 a	2.463 ab	10.36	130.1 c	108,400 a	11.6 a
TE 1.5 pt/a	2,975 b	2.548 c	10.53	108.7 a	130,856 bc	14.7 abc
CCC 1.34 lb ai/a	2,489 a	2.440 a	11.17	126.3 c	114,281 ab	11.6 a
TE 1.5 pt/a + CCC 0.67 lb ai/a	3,074 b	2.525 bc	8.11	111.5 ab	136,483 c	20.3 c
TE 1.5 pt/a + CCC 1.34 lb ai/a	3,112 b	2.471 ab	8.83	106.3 a	141,273 c	17.7 bc
TE 0.75 pt/a + CCC 0.67 lb ai/a	2,742 ab	2.489 abc	10.44	116.7 b	123,612 abc	13.3 ab

Treatment	Yield	Seed weight	Biomass	Height	Seed number	HI[2]
	--- Polk County ---					
	(lb/a)	(mg/seed)	(ton/a)	(cm)	(seeds/m²)	(%)
Untreated control	2,134 a	2.374 a	9.41 c	116.2 c	100,945 a	11.4 a
TE 1.5 pt/a	3,084 b	2.439 b	5.92 a	86.2 a	141,798 b	26.3 c
CCC 1.34 lb ai/a	2,177 a	2.375 a	9.87 c	111.4 bc	102,690 a	11.3 a
TE 1.5 pt/a + CCC 0.67 lb ai/a	3,227 b	2.443 b	6.30 ab	85.5 a	148,105 b	26.3 c
TE 1.5 pt/a + CCC 1.34 lb ai/a	3,252 b	2.388 a	6.83 ab	88.0 a	152,636 b	23.8 bc
TE 0.75 pt/a + CCC 0.67 lb ai/a	3,171 b	2.413 ab	8.68 bc	906.0 b	147,347 b	13.3 ab

Treatment	Yield	Seed weight	Biomass	Height	Seed number	HI[2]
	--- Linn County ---					
	(lb/a)	(mg/seed)	(ton/a)	(cm)	(seeds/m²)	(%)
Untreated control	2,184	2.511	10.04	114.1 b	97,517	10.9
TE 1.5 pt/a	2,197	2.588	8.99	98.4 a	95,165	13.1
CCC 1.34 lb ai/a	2,142	2.492	9.86	111.9 b	96,506	11.0
TE 1.5 pt/a + CCC 0.67 lb ai/a	2,270	2.592	10.36	99.6 a	98,294	11.1
TE 1.5 pt/a + CCC 1.34 lb ai/a	2,332	2.517	8.62	89.8 a	113,875	13.8
TE 0.75 pt/a + CCC 0.67 lb ai/a	2,302	2.519	8.05	97.0 a	111,529	14.6

Treatment	Yield	Seed weight	Biomass	Height	Seed number	HI[2]
	--------------------------------------- Benton County ---------------------------------------					
	(lb/a)	(mg/seed)	(ton/a)	(cm)	(seeds/m²)	(%)
Untreated control	2,405 ab	2.085	10.20	111.6 b	129,335 ab	12.0
TE 1.5 pt/a	2,734 c	2.045	9.81	91.8 a	150,032 c	14.2
CCC 1.34 lb ai/a	2,132 a	2.017	10.52	113.1 b	119,077 a	10.2
TE 1.5 pt/a + CCC 0.67 lb ai/a	2,648 bc	2.054	10.86	96.5 a	144,511 bc	12.2
TE 1.5 pt/a + CCC 1.34 lb ai/a	2,719 bc	1.979	9.64	89.3 a	154,064 c	14.3
TE 0.75 pt/a + CCC 0.67 lb ai/a	2,712 bc	1.988	9.82	99.2 a	152,863 c	14.2

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

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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

In Oregon's Willamette Valley, annual ryegrass (ARG) seed production typically occurs in fields with a history of ARG seed production, and volunteer ARG populations can be problematic when growers are establishing new ARG fields. Row spraying ARG at planting is a useful management tool for growers to manage volunteer ARG. However, effective herbicide options are limited. Axiom DF (flufenacet + metribuzin) is a preemergent herbicide commonly used for row spraying ARG seed production fields; approximately 48,000 acres (40%) of the ARG grown in the Willamette Valley are treated with Axiom DF annually (Hulting, 2013). In fields with a long history of ARG production, the most common practice is to apply Axiom DF preemergence between the rows when planting new ARG stands to suppress volunteer ARG emergence. This "Axiom-planting" practice also enables growers to plant fields earlier since they do not need to wait for rainfall to germinate the first flush of volunteer ARG in order to control emerged seedlings with a nonselective broadcast herbicide application prior to planting.

Since Axiom DF herbicide is used for weed management in ARG, perennial ryegrass, tall fescue, and wheat production, there is concern by OSU researchers and the grass seed industry that the continuous and widespread use of Axiom DF will lead to the development of resistant ARG. Such resistance is now suspected in Willamette Valley ARG and wheat production fields. To maintain Axiom as an effective herbicide in a variety of field crop production scenarios, a need exists to identify herbicides with different modes of action for row spraying purposes in order to build a resistance management strategy. The objective of this study was to evaluate several alternative herbicide products to determine row-spraying utility based on crop safety, row persistence, and seed yield.

Materials and Methods

Four field trials were conducted over two growing seasons to evaluate row spraying at planting in ARG seed production fields. Two trials were established during the fall of 2015 and harvested in 2016; the details are outlined in Sullivan et al., 2017. A second group of trials was established during the fall of 2016. A trial in Lebanon was planted to 'Winterhawk' on September 15, and a trial at Irish Bend was planted to 'Big Boss' on September 16. Seeding rate was 22 lb/acre for all trials.

All field 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 to spray while seeding. Both the drill and nozzles (4003) were at 10-inch spacing, and a 7.7-inch band of herbicide was sprayed between the drill rows. Herbicide treatments included in the trial are presented by product name, active ingredient, and application rate (Table 1).

Results and Discussion

The trial sites used in the 2016–2017 growing season had a long history of ARG and very heavy volunteer pressure. There was a large range in percentage control of volunteer ARG across the treatments (Table 2), which was very different than the consistently high annual bluegrass control rates observed in the 2015–2016 growing season (Sullivan et al., 2017).

Table 1. Herbicide treatments used for row spraying at planting in new annual ryegrass seed fields planted in fall 2015 and fall 2016.

Product	Active ingredient	Rate	Product rate
		(lb ai/a)	(oz/a)
Control	—	—	—
Axiom DF[1]	Flufenacet + metribuzin	0.425	10
Diuron[1]	Diuron	1.0	32
Metribuzin	Metribuzin	0.25	9.7
Kerb	Pronamide	0.375	8
Fierce	Pyroxasulfone + flumioxazin	0.095	2
Alion	Indaziflam	0.013	1
Matrix	Rimsulfuron	0.047	3
Everest	Flucarbazone	0.0273	1
Eptam	EPTC	3.5	64

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

Based on evaluations conducted at the end of March 2017, Fierce and Eptam provided the greatest (about 90%) and most consistent ARG control during the 2016–2017 growing season (Table 2). The metribuzin, Matrix, and Everest treatments all provided less than 25% control of volunteer ARG across both trial sites. The efficacy of diuron, Axiom DF, and Kerb varied by site. Diuron provided 69% control at the Lebanon site but only 5% control at the Irish Bend site, suggesting that the volunteer ARG populations at Irish Bend were tolerant to the rate of diuron used. Axiom DF resulted in only 67% volunteer ARG control at Lebanon but 91% at Irish Bend, while Kerb provided 85% control at Lebanon and only 58% control at Irish Bend.

The majority of the herbicide treatments resulted in about 10 to 20% crop injury at both sites (Table 2). However, the observed crop injury in March 2017 did not correspond to seed yield differences between treatments. Yields were very low at the Lebanon site due to a very significant amount of seed shatter at swathing and high winds disturbing the swaths. The results were very low yields and no separation between treatments (Table 2).

At the Irish Bend site, there was a trend toward higher seed yield in the Axiom DF treatment (2,331 lb/acre) as compared to the check and a trend showing lower yields with Kerb (1,153 lb/acre) and Alion (1,007 lb/acre) as compared to the check (Table 2).

Conclusions

We were able to collect reliable crop injury data from 2 years of trials, and results consistently showed no correlation between crop injury and seed yield. While weed pressure was too low in 2015–2016 for reliable control data, the 2016–2017 trials provided very realistic results from the use of these herbicide treatments for row spraying at planting in fields with heavy volunteer ARG pressure. Consistently over the 2 years of trials, Fierce provided the greatest and most consistent weed control between rows (*Poa* spp. and volunteer ARG).

The excellent control (greater than 90%) of *Poa* spp. observed in the metribuzin and Matrix treatments in 2015–2016 had some growers and fieldmen very interested, but these same products provided less than 30% control of volunteer ARG in 2016–2017. This

Table 2. Volunteer annual ryegrass control, crop injury, and clean seed yield results at two sites harvested in 2017.

	-- Volunteer control --		----- Crop injury -----		--------- Seed yield[1,2] ---------	
Product	Lebanon	Irish Bend	Lebanon	Irish Bend	Lebanon	Irish Bend
	------------------------- (%)[3]	-------------------------			------------ (lb/a)	--------------
Control	0	0	0	0	37 a	1,438 ab
Axiom	67	91	12	16	173 a	2,331 a
Diuron	69	5	10	3	236 a	1,524 ab
Kerb	85	58	4	8	198 a	1,153 b
Metribuzin	23	11	8	4	296 a	1,512 ab
Fierce	96	94	20	11	166 a	1,685 ab
Alion	59	56	11	13	297 a	1,007 b
Matrix	19	15	10	11	285 a	1,476 ab
Everest	15	23	10	19	217 a	1,441 ab
Eptam	89	88	16	16	273 a	1,775 ab
LSD (P = 0.05)					184	618
CV					58	28

[1]Lebanon was swathed June 28, 2017 and harvested July 12. Irish Bend was swathed June 28, 2017 and harvested July 17.
[2]Means followed by the same letter within the same column are not significantly different at LSD (P = 0.05).
[3]Control and crop injury evaluated March 31, 2017 at Lebanon and March 25, 2017 at Irish Bend.

was a very important observation, as the 2016–2017 trials tested these products under high volunteer ARG pressure, and they performed much differently than in the low-pressure fields of the first year of trials. The weed control performance of Kerb, Alion, and Everest also decreased with the heavy volunteer ARG pressure in the second year of trials. Axiom DF, the product currently used for row spraying at planting, varied in its weed control performance across all 4 site years from 67 to 92% control.

Axiom-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. Based on these 2 years of data, there was no difference in yield between any of the treatments, including the untreated control. These preliminary studies show no advantage to row spraying at planting over conventional seeding, and none of the herbicide products tested in this experiment stand out as viable alternatives for Axiom DF. Fierce is the only product with potential; however, using Fierce would not be helpful for resistance management, as flufenacet and pyroxasulfone are the same mode of action. The injury potential and variability in efficacy from year to year with Kerb, Eptam, and Alion are too great to pursue registration for this use of these products.

In this study there was no measurement of other benefits that may be associated with row spraying, such as ease of straw management and harvest. Decreased biomass may allow for faster travel speeds at swathing and combining, resulting in increased harvest efficiency. Growers have reported that the reduction in overall straw load can be beneficial for slug management and future seedbed preparation.

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INVESTIGATING THE IMPACT OF ROW SPRAYING ON ESTABLISHED WHITE CLOVER

C.S. Sullivan, K.C. Roerig, and A.G. Hulting

Introduction

White clover seed producers in the Willamette Valley struggle with highly variable yields from year to year. Seed yield depends primarily on flower head density, which in turn is affected by environment, management, and cultivar (FAR, 2006). In Oregon, white clover seed yields vary widely due to the difficulty in managing crop vigor with grazing and to variable weather patterns. Researchers in New Zealand have increased white clover seed yield and stability by refining the time sheep are removed from the field, adopting optimal irrigation practices and row spacing, and managing second-year growth with herbicides.

White clover spreads by stolons. Flowers are produced on the tips of stolons, as long as the stolons continue to grow outwards. Therefore, creating the proper conditions for stolon elongation is deemed a critical contributing factor for maximum seed yield. Second-year growth needs to be managed to allow light to reach the growing points of primary stolons and to create space for primary stolons to grow outwards. If stolons are limited by light and space, the viability of reproductive seed heads will be decreased.

Optimal production of primary stolons is hard to manage with grazing or mowing alone, as over-grazing leads to high production of secondary and tertiary stolons. 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 plant density. Recently, row spraying with herbicides has been used to optimize primary stolon number and length, as well as flower density (Thomas et al., 2009).

Willamette Valley growers are interested in the feasibility of row spraying in rain-fed 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 application timing need to be evaluated to know whether row spraying is a viable tool.

The goal of this research was to evaluate the effectiveness of row spraying in second-year white clover seed 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, crop tolerance, and 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 2017 on a second-year stand of ladino-type white clover ('VNS') established at Hyslop Research Farm in the fall of 2015. This was the second trial year of this experiment; the first year of the trial was conducted in 2016 on a second-year white clover stand (Sullivan et al., 2017). The stand was not fertilized, and no pesticide applications outside of 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.

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 timings in the late winter/early spring of 2017, resulting in a total of 24 treatment combinations (Table 2). The sprayer was

Table 1. Herbicide treatments used for row spraying in established white clover stands. ***None of the listed herbicide treatments is 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.

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.

The three herbicide application timings in 2017 were: "early timing" (January 26), "mid timing" (April 3), and "late timing" (May 4). The intention was to advance the row spray timings in 2017 as compared to 2016, aiming for timings in early January, mid-February, and mid-March. However, due to difficult weather conditions from January onward, we were unable to move up the second and third spray times to our desired intervals. Sheep did not graze the field, but the trial was mowed on April 19 and the residues were removed from the field with a forage harvester.

Plots were visually evaluated for row persistence and crop injury six times between March 13 and May 31, 2017. Flower head density was measured once on June 22 by counting the number of flowers in two 0.5 m^2 quadrats per plot. The white clover crop was swathed on August 1 and combined on August 7. Harvested seed was cleaned, and yield was calculated. Seed germination counts for seed quality measurements have yet to be completed.

Table 2. Average white clover flower head density and seed yield of the 24 row spraying treatments in 2017. Ranked from highest to lowest seed yield.[1]

Treatment	Herbicide	Timing	Flower density[2]	Seed yield
			(heads/ft^2)	(lb/a)
24	Control	—	23 abcd	356 a
4	Goal	Early	23 abcd	354 ab
7	Sharpen broadcast	Early	23 abcd	346 ab
5	Rely	Early	21 abcde	344 ab
2	Alion + Rely	Early	22 abcd	342 ab
23	Control	—	20 abcde	340 abc
8	Chateau	Early	24 ab	336 abcd
6	Sharpen	Early	18 bcde	324 abcd
1	Control	—	24 ab	314 abcde
22	Chateau	Late	27 a	300 abcdef
11	Goal	Mid	25 ab	293 bcdefg
3	Express	Early	14 cdef	278 cdefgh
15	Chateau	Mid	23 abc	276 defgh
18	Goal	Late	26 ab	261 efgh
13	Sharpen	Mid	12 ef	260 efgh
9	Alion + Rely	Mid	21 abcde	246 fghi
14	Sharpen broadcast	Mid	12 ef	236 ghi
12	Rely	Mid	18 bcde	229 hi
19	Rely	late	22 abcd	191 ij
17	Alion + Rely	Late	20 abcde	185 ij
20	Sharpen	Late	19 abcde	181 ij
21	Sharpen broadcast	Late	14 cdef	160 j
16	Express + Rely[3]	Late	14 def	131 jk
10	Express	Mid	8 f	84 k
LSD (*P* = 0.05)				62

[1]Means followed by the same letter within the same column are not significantly different at LSD (*P* = 0.05).
[2]Flower head counts taken on June 22, 2017.
[3]Rely was added to the late Express treatment by accident; there is no late treatment of Express alone.

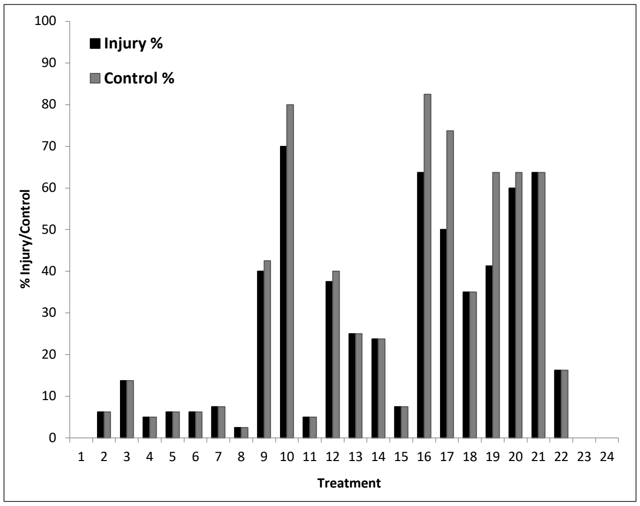

Figure 1. Percent crop injury and percent control (row persistence) in each treatment evaluated on May 31, 2017. Treatments 1, 23, and 24 are control plots, 2 to 8 are early application, 9 to 15 are mid application, and 16 to 22 are late application.

Results and Discussion

The final visual evaluation conducted on May 31, 2017 revealed low crop injury and low row persistence in the early application plots, with significantly higher crop injury and row persistence for the mid and late row spray timings (Figure 1). Crop injury was much higher at the mid application timing in 2017, as compared to the 2016 trial, likely due to an excessive amount of clover foliage at the mid application timing in 2017.

Flower head density counts taken June 22 revealed very similar flower head densities between the control plots and the Goal and Chateau herbicide treatments applied at any timing (Table 2). For any given treatment timing, none of the treatments evaluated were significantly different, compared to the untreated control ($22/ft^2$). However, average flower head density was significantly reduced in the mid treatment timing ($17/ft^2$).

None of the row-spray treatments resulted in higher seed yields, compared to the untreated control plots, but six out of seven of the early timing row spray treatments yielded as high as the control plots (Table 2). Average seed yield for the early treatments was 332 lb/acre, which was as high as the control plots and significantly greater than the mid (232 lb/acre) and late (201 lb/acre) application timings. There was no direct correlation between flower head density and clover seed yield. Goal and Chateau resulted in relatively higher seed yields, but only with the early row spray timing.

Conclusion

In both study years, early row spray treatments of Goal (treatment 4) and Chateau (treatment 8) stood out as the herbicide treatments with relatively highest flower head densities and seed yields. However, they did not yield significantly higher than the untreated control. Visually, these treatments most closely resembled the untreated control plots with low crop injury and low control (row persistence), indicating that the treatments that performed best were those that essentially acted as control plots.

Based on these two years of data, there is no seed yield benefit from row spraying second-year white clover fields, especially with the added cost and time required to make an additional herbicide application. If future row spraying trials are pursued, it is advised to look at timings between December to early March at the latest.

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COLD TOLERANCE EVALUATION OF FOUR ANNUAL RYEGRASS VARIETIES GROWN IN OREGON USING A THERMOGRADIENT TABLE

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Introduction

The use of annual ryegrass (*Lolium multiflorum* L.) as a winter cover crop by Midwest corn and soybean farmers has opened a market for Oregon ryegrass seed growers. The advantage of annual ryegrass (ARG) over other cover crops is its ability to grow on poorly drained soil under no-till farming systems (Hart et al., 2011). In addition, ARG is generally not hard to kill in the spring after it fulfills its function as a cover crop in the fall and winter, provided recommended management practices are followed (Plumer et al., 2016).

One of the main challenges of using ARG as a cover crop in the Midwest is selecting appropriate varieties that tolerate low temperatures (approximately 5–10°C; 41–50°F) and produce good stand establishment in a cold environment. Although ARG is a cool-season grass, some varieties have better cold tolerance than others, depending on the genetic makeup of each variety.

Asomaning et al. (2011) reported that using a thermogradient table is an effective tool for predicting seed germination under cold climatic conditions (5–15°C; 41–59°F). This technology is a practical device for screening Oregon ARG varieties to determine which ones have the best potential for quick germination under temperatures similar to those in the Midwest during autumn months. Although planting in September is suggested in the northern Corn Belt and by mid-October in the southern Corn Belt, above-normal rainfall in some years may delay planting. In such cases, seeds have to germinate under suboptimal soil temperatures. Consequently, the ARG varieties that can tolerate cold have a better chance of quick, uniform emergence. This study was designed to use thermogradient technology to screen four ARG varieties for germination cold tolerance.

Materials and Methods

Approximately 500 grams of seed from Oregon-grown varieties, including 'Bounty', 'KB Royal', 'Ed', and 'Gulf', were used in this study. Tetrazolium tests were conducted on the four varieties to determine the initial viability level. A total of 240 seeds of each variety were planted on the thermogradient table. The temperature range at which seeds were planted was 5–25°C (41–77°F). Sections were divided into four increments: 5–10°C (41–50°F), 11–15°C (52–59°F), 16–20°C (61–68°F), and 21–25°C (70–77°F). The number of germinating seeds (both root and shoot emergence 0.5 cm or longer) was counted and reported at day 5, 9, and 14. Average seedling height was measured and recorded on day 14, which was the last day of the study.

Speed of germination indices (SGI) were calculated at the end of the trial using an established protocol to measure seed vigor. The higher the SGI, the faster the germination and the higher the seed quality.

Varieties with higher and faster germination index scores at lower temperatures indicate better potential emergence success in the Midwest environment. Mean SGI and standard deviation (SD) were used to identify and rank varieties for cold tolerance.

Results and Discussion

Two factors are considered when testing for cold tolerance of ARG. The first is the speed of germination (i.e., how fast the seeds germinate) under cold temperatures (especially the 5–10°C range) before colder weather arrives in late fall in the Midwest. The second is seedling height before temperatures drop to the freezing point. Reasonable seedling size (5–6 inches) is needed for the plant to survive through the winter. Smaller seedlings are more susceptible to winter kill.

Initial viability of seed samples

The initial viability by tetrazolium (TZ) tests of 'Bounty', 'KB Royal', 'Ed', and 'Gulf' was 98%, 98%, 97%, and 97%, respectively. This indicates that high and similar quality seeds were used in the study. Thus, most of the variation among varieties for cold tolerance would be due to genetic factors rather than variation in seed quality.

Germination at 5–10°C (41–50°F) range

Five days after planting, none of the seeds from any of the varieties had germinated at the temperature range of 5–10°C (41–50°F) (Figure 1). This temperature range is critical to determine the extent of cold tolerance of an annual ryegrass variety because the soil temperature in the Midwest during late fall planting is within this

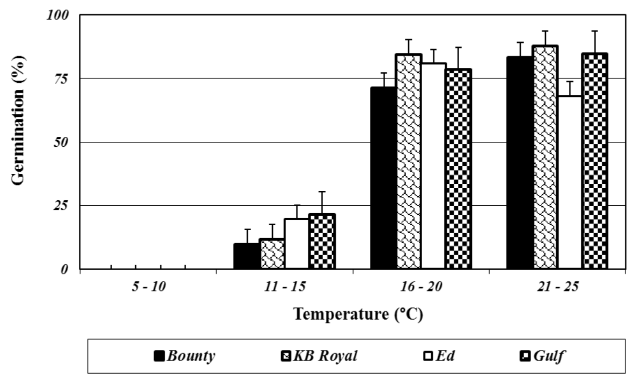

Figure 1. Germination rates of four annual ryegrass varieties after 5 days in a thermogradient table at four temperature ranges (5–10°C, 11–15°C, 16–20°C, and 21–25°C).

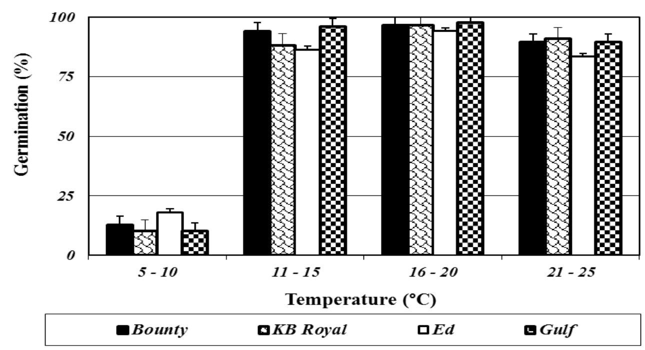

Figure 2. Germination rates of four annual ryegrass varieties after 9 days in a thermogradient table at four temperature ranges (5–10°C, 11–15°C, 16–20°C, and 21–25°C).

Table 1. Speed of germination index (SGI) and average seedling height of four annual ryegrass varieties grown at four temperature ranges in a thermogradient table.

	Speed of germination index (SGI) ------------------ over 14-day test period[1] ------------------				
Temperature range	Bounty	KB Royal	Ed	Gulf	Average seedling height on day 14[2]
(°C)					(inches)
5–10	2	2	2	2	1.2
11–15	6	6	6	7	2.5
16–20	14	15	15	15	4.3
21–25	11	12	10	12	6.0

[1]Gradual increase in the speed of germination occurred as the temperature increased. The level of seed vigor of each variety affects the SGI.
[2]As the germination temperature increased, seedling height increased. At a temperature range of 5–7°C, seedling height was about 0.5 inch; at 8–10°C, it was about 1.4 inches.

range. After 9 days, 'Ed' had the highest germination rate at 18%, while 'KB Royal' and 'Gulf' had the lowest at 10% (Figure 2). The SD of germination among the four varieties was 3.6. After 14 days, 'KB Royal' and 'Bounty' had the highest germination rates of 82% and 79%, respectively, whereas Gulf and Ed had the lowest at 67% and 64%, respectively (Figure 3). The large difference in germination rate was reflected by a SD of 9.0.

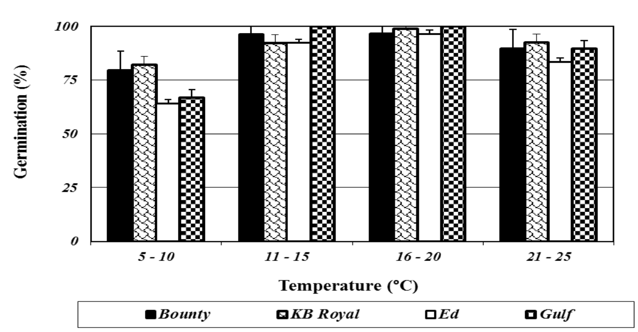

Figure 3. Germination rates of four annual ryegrass varieties after 14 days in a thermogradient table at four temperature ranges (5–10°C, 11–15°C, 16–20°C, and 21–25°C).

The SGI is an indication of speed of germination and seed vigor. The higher the index, the better the quality of the seed. At the temperature range of 5–10°C, the SGI was 2 for all varieties (Table 1), which provides evidence that the four varieties had a similar, low speed of germination and cold tolerance. There was no superiority of one variety tested over another.

The average seedling height of the plants germinated at 5–10°C on day 14 was 1.2 inches (Table 1). As temperatures get closer to 5°C, the seedling size got smaller. At a temperature range of 5–7°C, the seedling height was approximately 0.5 inch, and at 8–10°C, it was approximately 1.4 inch. In general, as germination temperature increased, seedling height increased. Planting earlier in the fall when soil temperatures are higher than 5–10°C could increase the chance for better and faster stand establishment.

Germination at 11–15°C (52–59°F) range

Five days after planting, the germination rates of 'Bounty', 'KB Royal', 'Ed', and 'Gulf' at the temperature range of 11–15°C were 10%, 12%, 20%, and 22%, respectively (Figure 1). After 9 days, 'Gulf' and 'Bounty' had the highest germination rates at 96% and 94%, respectively, followed by 'KB Royal' and 'Ed' with germination rates of 88% and 86% (Figure 2). After 14 days, 'Gulf' and 'Bounty' also had the highest germination rates at 100% and 96%, respectively, followed by 'KB Royal' and 'Ed' with a germination rate of 92% for both varieties (Figure 3).

At a temperature range of 11–15°C, the SGI was 6, 6, 6, and 7 for 'Bounty', 'KB Royal', 'Ed', and 'Gulf', respectively. It is evident that varieties had similar SGI and cold tolerance.

The average seedling height of the plants germinated at 11–15°C on day 14 was 2.5 inches. This seedling size is too small for overwinter conditions in the Midwest. Planting earlier in the fall, when soil temperatures are above 15°C (59°F), is recommended to obtain larger seedlings.

Germination at 16–20°C (61–68°F) range

Five days after planting, the germination rates of 'Bounty', 'KB Royal', 'Ed', and 'Gulf' at the temperature range of 16–20°C were 71%, 85%, 81%, and 79%, respectively (Figure 1). 'Bounty' had the lowest germination rate at this temperature range. After 9 days, the germination rates of 'Bounty', 'KB Royal', 'Ed', and 'Gulf' at the same temperature range were 96%, 96%, 94%, and 98%, respectively (Figure 2). The final germination rates at this temperature range after 14 days were 96%, 99%, 96%, and 100% for 'Bounty', 'KB Royal', 'Ed', and 'Gulf', respectively (Figure 3). Obviously, at the temperature range of 16–20°C, the germination rates of all varieties reached near maximum by day 14. At this temperature range, the SGI was 14, 15, 15, and 15 for 'Bounty', 'KB Royal', 'Ed', and 'Gulf', respectively. It is evident that at this temperature range all varieties had a similar high SGI. This is not unusual because this range of temperatures is optimum for growing cool-season grasses. The average seedling height of the plants germinated at 16–20°C after 14 days was 4.3 inches (Table 1). As the temperature range of germination increased, seedling size increased.

Germination at 21–25°C (70–77°F) range

Five days after planting, the germination rates of 'Bounty', 'KB Royal', 'Ed', and 'Gulf' at the temperature range of 21–25°C were 83%, 88%, 68%, and 85%, respectively (Figure 1). 'Ed' had the lowest germination rate at this temperature range. After 9 days, the germination rates of 'Bounty', 'KB Royal', 'Ed', and 'Gulf' were 89%, 91%, 83%, and 89%, respectively (Figure 2). The final germination percentages at the temperature range of 21–25°C after 14 days were 89%, 92%, 83%, and 89% for 'Bounty', 'KB Royal', 'Ed', and 'Gulf', respectively (Figure 3). The germination of 'Ed' did not improve between 9 and 14 days. This might be due to a seed vigor issue rather than cold tolerance trait.

At the temperature range of 21–25°C, the SGI was 11, 12, 10, and 12 for 'Bounty', 'KB Royal', 'Ed', and 'Gulf', respectively (Table 1). It is evident that all varieties had a similar speed of germination. The average seedling height of the plants germinated at 21–25°C after 14 days was 6 inches (Table 1). Again, as the temperature range for germination increased, seedling size increased. Seedling size of 6 inches is a reasonable size for winter survival.

Conclusion

There was no consistent pattern of superiority of one variety tested over another in terms of cold tolerance over the four germination temperature ranges used in the study. Planting earlier in the fall, when soil temperatures are approximately 15°C (59°F) or above is recommended for better and faster stand establishment. As the temperature range of germination increases, so does seedling height, which is important to maintain good stand establishment throughout the winter and reduce the rate of winter kill. The thermogradient table proved to be an effective tool to screen annual ryegrass varieties for cold tolerance. Finally, cold tolerance, quick emergence, and reasonable seedling size are keys for successful stand establishment of annual ryegrass as a cover crop in cold climates such as the Midwest.

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