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DISTRIBUTION AND FREQUENCY OF ITALIAN RYEGRASS HERBICIDE RESISTANCE IN THE WILLAMETTE VALLEY

L.K. Bobadilla, P.A. Berry, A.G. Hulting, and C.A. Mallory-Smith

Introduction

Weed management is one of the most challenging parts of any agricultural system, and herbicide resistance plays a significant role in management decision-making. Herbicide-resistant Italian ryegrass (*Lolium perenne* spp. multiflorum) is a management issue for growers worldwide, with more than 200 cases of unique resistant biotypes reported (Heap, 2018).

The vast majority of Oregon's Willamette Valley agriculture is based on grass seed production, which requires growers to achieve a premium level of seed purity. Without successful weed control, seed lots can be contaminated with Italian ryegrass seeds that carry herbicide resistance traits. Knowing the current distribution of herbicide-resistant biotypes and how commonly they can be found can help growers avoid contamination and prioritize management of resistant biotypes.

Field surveys have been done in many states and countries to understand the distribution and frequency of a weed and resistant biotypes (Hanson et al., 2009; Hanzlik and Gerowitt, 2016; Lutman et al., 2009; Owen and Powles, 2009). However, this type of study has not been done in Oregon with Italian ryegrass. The objective of this study was to document the distribution and frequency of multiple types of herbicide-resistant Italian ryegrass biotypes in western Oregon.

Materials and Methods

A 2-year survey was conducted during the summers of 2017 and 2018 in the ecoregion of the Willamette Valley in Oregon. The sites surveyed were randomly selected using available data from USDA CropScape regarding crop geospatial location (Han et al., 2012). For each year of the survey, a different randomization was utilized. The focus was to select fields where tall fescue or wheat crops were present. However, CropScape data were not precise enough to differentiate grass species, and many of the randomized geographic locations were grass species other than tall fescue and even other types of crops. These locations in other crops were surveyed, but if the field contained annual or perennial ryegrass as a crop, it was not included in the survey. Each site was at least 2 miles from the nearest site to best represent the surveyed area and also to determine whether there were any spatial clusters of herbicide resistance.

This survey used a stratified randomized design, with the Willamette Valley divided into three strata (north, central, and south) according to agricultural land acreage of the crops of interest. Four hundred fifty sites were randomly selected, and 150 of these sites were surveyed. At each site, the following information was collected: presence of the weed, Italian ryegrass density level (high = 20 or more plants/m^2; medium = 10–19 plants/m^2; low = fewer than 10 plants/m^2), GPS coordinates, and type of crop cultivated.

If Italian ryegrass was present, seed heads were collected, and progeny of these seeds were tested for herbicide resistance under greenhouse and laboratory conditions. Nine herbicides were tested for resistance, including six postemergent (Table 1) and three preemergent (Table 2) products.

Table 1. Postemergent herbicides and rates used for greenhouse screening test.

WSSA group	Active ingredient	Mode of action[1]	Trade name	Rate
				(lb/a)
1	Quizalofop-P-ethyl	ACCase inhibitor	Assure II	0.750
1	Clethodim	ACCase inhibitor	SelectMax	1.000
1	Pinoxaden	ACCase inhibitor	Axial XL	1.020
2	Pyroxsulam	ALS inhibitor	Powerflex HL	0.125
9	Glyphosate	EPSPs inhibitor	Makaze	2.000
22	Paraquat	PS I inhibitor	Gramoxone SL 2.0	0.250

[1]ACCase = acetyl-CoA carboxylase enzyme; ALS = acetolactate synthase; EPSPs = 5-enolpyruvylshikimate-3-phosphate synthase; PS I = photosystem I

Table 2. Preemergent herbicides and rates used for resistance screening in laboratory.

WSSA group	Active ingredient	Mode of action[1]	Trade name	Rate
				(µM)
15 + 5	Flufenacet + metribuzin	VLCFA inhibitor	Axiom	2.20
15	Pyroxasulfone	VLCFA inhibitor	Zidua	0.98
5	Pronamide	Microtubule assembly inhibition	Kerb	1.40

[1]VLCFA = very-long-chain fatty acid

The postemergence resistance screening test was done in the greenhouse using a complete randomized design with four replications. Each replication consisted of a square tray (9 inches x 9 inches), with 16 Italian ryegrass plants per tray. Plants were sprayed when the seedlings reached an average height of 6 inches and the two-leaf growth stage. Visual survival rate and image analysis for green area measurement were collected 21 days after treatment.

Preemergence resistance screening was completed using a seed germination assay in germination boxes (4⁵⁄₁₆ inches x 4⁵⁄₁₆ inches x 1⅜ inches) containing 1% agarose media with a known rate of each herbicide (Murray et al., 1996). Application rates were determined by a dose-response assay with known susceptible populations. Four replications with 16 seeds per germination box were used in complete randomized design. Visual germination rate and image analysis for green area measurement were collected 12 days after seed placement in the media.

Resistance levels were classified as susceptible (0–2% survival), developing resistance (2–19% survival), and resistant (20% or more survival). This classification was made based on survival rate and green leaf-area reduction compared to an untreated control. For fields where Italian ryegrass was not found, it was assumed that if any Italian ryegrass was present in the field it was controlled during the season and therefore classified as susceptible. Resistance types were classified as multiple (resistance to more than one mode of action), cross (resistance to more than one herbicide that acts at the same site of action), and single (resistance to only one specific herbicide).

A binomial logistic analysis was used to check whether the probability of finding the weed present and herbicide resistance was related to altitude, location, or type of crop. The frequency of weed presence and resistance was calculated using the Survey package with R software. A multispatial cluster analysis and a nearest neighbor spatial analysis were made using ArcGIS to determine whether any spatial clusters of herbicide resistance were present.

Results and Discussion

Overall, Italian ryegrass was present in 75 of the 150 fields surveyed during the 2-year study (Tables 3 and 4). Regarding density, 21.33% of the surveyed fields had a high density (20 plants or more/m^2), 10.67% had a medium density (10–19 plants/m^2), and 18% had a low density (fewer than 10 plants/m^2). With respect to herbicide resistance, 36.67% of the fields surveyed had some form of herbicide resistance present (Figure 1).

Table 3. Frequency of Italian ryegrass presence in surveyed counties.

County	Not present	Present	Total	Frequency
	-------------- (no.)	--------------		(%)
Benton	27	21	48	43.75
Clackamas	0	1	1	100.00
Linn	4	8	12	66.67
Marion	20	18	38	47.37
Polk	7	8	15	53.33
Washington	9	9	18	50.00
Yamhill	8	10	18	55.56
Total	75	75	150	50.00

Table 4. Frequency of Italian ryegrass presence in each stratum.

Stratum	Not present	Present	Total	Frequency
	--------------- (no.)	--------------		(%)
Center	25	25	50	50
North	22	28	50	56
South	28	22	50	44
Total	75	75	150	50

Regarding presence of multiple-resistant biotypes, 23.33% carried resistance traits to more than one mode of action. The most common type of herbicide resistance was to herbicides with the mode of action known as ACCase (acetyl-CoA carboxylase enzyme) inhibitors; 25% of the surveyed fields had resistant traits present to at least one herbicide of this group (Figure 2). The most common multiple-resistance combination was to herbicides in the ACCase and ALS (acetolactate synthase) inhibitor mode of action groups (Figure 3). These results confirm what growers and agronomists have observed in the field for many years regarding herbicides in the EPSPs, ALS, and ACCase inhibitor mode of action groups. These products are no longer providing good control of Italian ryegrass, indicating widespread herbicide resistance throughout the Willamette Valley.

Among the herbicides tested in the study, resistance levels varied (Figure 4). The most effective herbicide tested was pyroxasulfone, which controlled 99% of all tested populations. To date, no resistance has been documented to pyroxasulfone, and it is possible this active ingredient will be relied upon in the future to control resistant populations.

The density of Italian ryegrass plants varied by stratum (data not shown). Where Italian ryegrass was present, 42.67% of locations had a high density of Italian ryegrass present, while 36% and 21.33% of locations had low and medium levels of Italian ryegrass density, respectively. Herbicide resistance was present in all three density levels and was unrelated to density level.

The average nearest neighbor ratio analysis showed that significant spatial clusters were found with respect to the presence of multiple resistance, indicating that some regions of the Valley present a concentration of this type of resistance

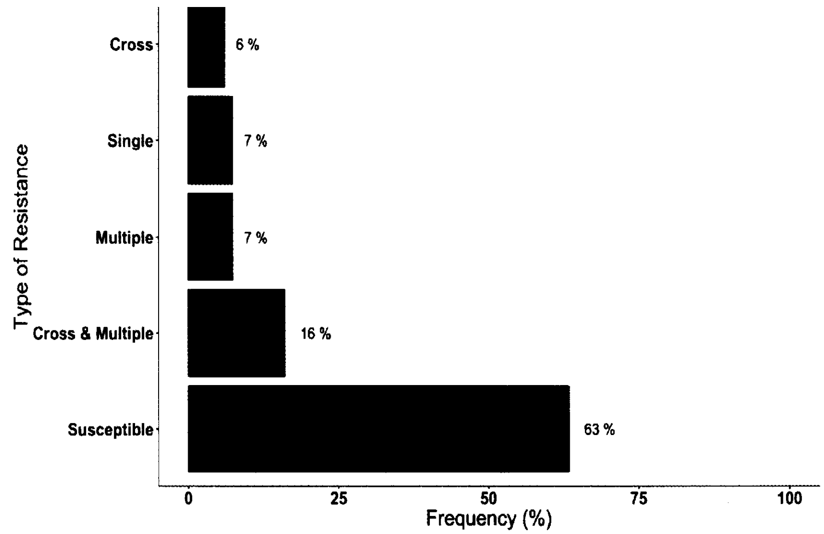

Figure 1. Frequency of presence of different types of herbicide resistance in Italian ryegrass.

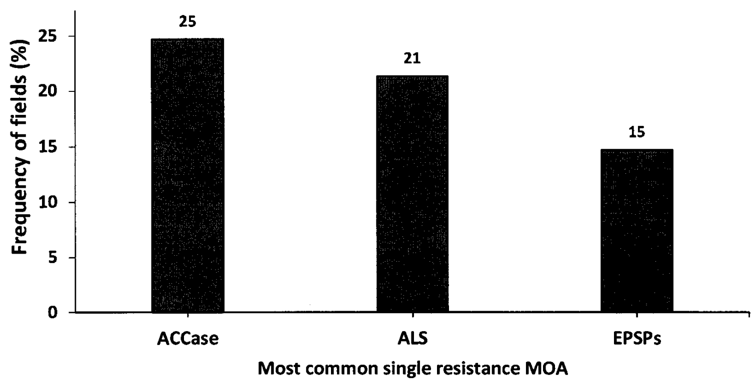

Figure 2. Frequency of the most common mode of action (MOA) resistance cases in Italian ryegrass.

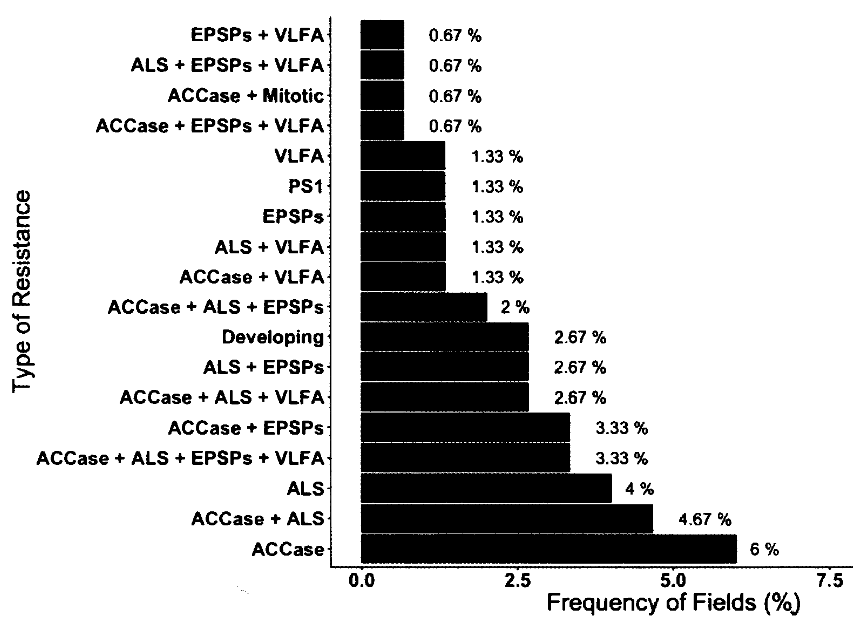

Figure 3. Frequency of specific types of single and multiple resistance in populations of Italian ryegrass in surveyed fields.

(data not shown). In contrast to one of our hypotheses, the binomial-logistic analysis indicated that Italian ryegrass presence and resistance to any herbicide is not related to the specific stratum location, altitude, or type of crop (data not shown). Future studies should focus on trying to understand what factors affect the presence and proportion of certain types of herbicide resistance in a given area.

Conclusion

Results from this study indicate widespread distribution of herbicide-resistant Italian ryegrass in the Willamette Valley, with some populations exhibiting resistance to multiple herbicide mode of action groups. It is theorized that these resistant populations developed over many years due to intense selection pressure resulting from repeated application of herbicides with similar modes of action. However, the herbicide assay revealed alternative and effective herbicide options, such as pyroxasulfone, which could help reduce resistant Italian ryegrass populations.

Some specific locations presented clusters of populations with multiple-resistance traits, indicating that some regions are selecting for multiple-resistant populations.

To our knowledge, this is the first study in Oregon that shows the current status of herbicide-resistant Italian ryegrass in the Willamette Valley. It should provide the basis for future studies to investigate factors that influence mechanisms of resistance in the Willamette Valley.

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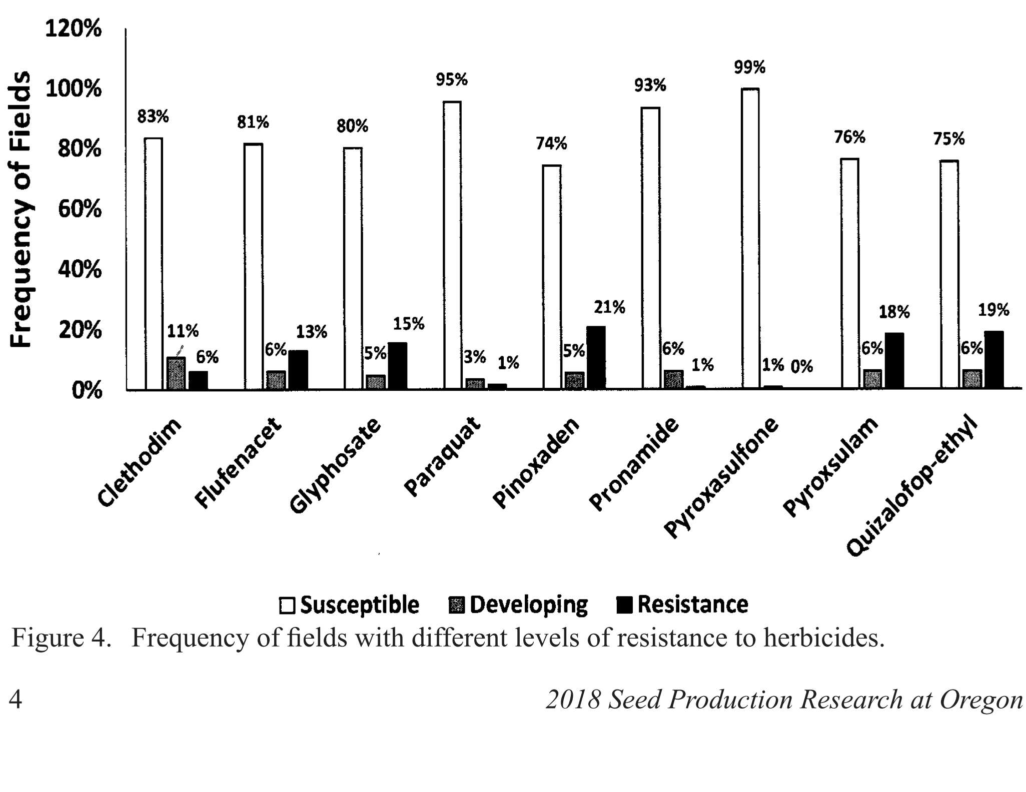

Figure 4. Frequency of fields with different levels of resistance to herbicides.

MANAGEMENT OF ANNUAL RYEGRASS CONTAMINATION IN TALL FESCUE AND ORCHARDGRASS GROWN FOR SEED

D.W. Curtis, K.C. Roerig, A.G. Hulting, C.A. Mallory–Smith, and N.P. Anderson

Introduction

Annual ryegrass contamination is a serious management issue in the production of tall fescue and orchardgrass grown for seed. Annual ryegrass seed is very similar in size to tall fescue seed, making cleaning nearly impossible. In orchardgrass, there is a seed size differential, but cleaning losses and competitive losses in the field can be substantial. Two studies in commercial plantings of tall fescue and orchardgrass documented management of annual ryegrass populations in these cropping systems. Study 1 was located in a commercial planting of tall fescue just north of Forest Grove, OR, and utilized sequential herbicide treatments to manage a population of annual ryegrass. Study 2 was conducted in a commercial planting of orchardgrass, located east of Adair, OR, and utilized a similar set of sequential treatments to attempt management of an annual ryegrass population.

Materials and Methods

Both the Forest Grove study and the Adair study utilized randomized complete block designs with four replications. Plot size in both studies was 8 feet x 25 feet. Herbicide treatments were applied with a research sprayer calibrated to deliver 20 gpa at 20 psi. Visual crop injury and visual percent control of both volunteer crop seedlings and annual ryegrass were evaluated at both locations. The seed from both studies was harvested by first swathing plots with a modified JD 2280 swather, followed by thrashing with a Wintersteiger Nursery Master combine in the tall fescue study and a Hege 180 combine in the orchardgrass study. Seed was cleaned using a Clipper Cleaner, and yield results were analyzed using ANOVA and means separated by LSD.

Study 1

Study 1 was initiated in an established commercial tall fescue seed production field going into its fifth harvest near Forest Grove. Originally, the intent of the study was to attempt to manage annual bluegrass, but annual bluegrass did not emerge. Annual ryegrass did emerge, and treatment differences were observed and quantified.

The site had received precipitation totaling 1.2 inches just prior to marking out the site on October 1, but at this time weeds had not emerged. A uniform crop area was located for the study, and a decision was made to apply herbicide treatments just prior to the next rain event. Initial treatments consisted of Axiom (flufenacet/metribuzin), Axiom + diuron, Axiom + Goal (oxyfluorfen), Fierce (pyroxasulfone/flumioxazin), Fierce + diuron, and Fierce + Goal (Table 1). Initial treatments were made on October 9, 2014 (Table 2) and were incorporated with rainfall from October 11 through October 15, with more than an inch of precipitation.

A second sequence of treatments was applied on November 20 (Tables 1 and 2). Treatments included Axiom and Fierce applied alone to previously treated plots of either Axiom + Goal or Fierce + Goal, Outlook (dimethenamid-P) + Rely (glufosinate) applied to initial treatments of Axiom + Goal or Fierce + Goal, and a mixture of Fierce + Rely + Nortron (ethofumesate) + Sharpen (saflufenacil) applied to an Axiom initial treatment. Rainfall continued in a normal pattern, providing good soil moisture steadily through the fall and winter.

Table 1. Treatments for management of grass weeds in tall fescue grown for seed, 2014–2015.

Treatment[1]	Rate	Timing[2]
	(lb ai/a)	
Untreated	0	A
Axiom	0.55	A
Axiom + diuron	0.55 + 1.0	A
Axiom + Goal	0.55 + 0.06	A
Axiom + Goal fb	0.55 + 0.06	A
Fierce	0.14	B
Fierce	0.14	A
Fierce + diuron	0.14 + 1.0	A
Fierce + Goal	0.14 + 0.06	A
Fierce + Goal fb	0.14 + 0.06	A
Axiom	0.55	B
Axiom + Goal fb	0.55 + 0.06	A
Outlook + Rely	0.98 + 0.3	B
Fierce + Goal fb	0.14 + 0.06	A
Outlook + Rely	0.98 + 0.3	B
Axiom fb	0.55	A
Fierce + Nortron	0.14 + 1.0	B
+ Rely + Sharpen	0.3 + 0.04	B

[1]fb = followed by
[2]A = Oct. 9, 2014; B = Nov. 20, 2014

Study 2

A study was established in a 7-year-old commercial orchardgrass seed production field (located east of Adair) during the fall of 2017 to target annual ryegrass control. Following a meeting with the grower and a field representative from a local ag service provider, an area of the field was located to establish the study where the grower suspected annual ryegrass pressure.

The site had received 1.5 inches of rainfall just prior to this meeting, and at this time no weed seedlings had emerged. The area was staked the following week, and the first set of herbicide applications was made on October 6, 2017 prior to anticipated rainfall. Herbicide treatments were incorporated with rainfall starting October 10, with 1.18 inches by October 14. At this timing, both volunteer crop and annual ryegrass had begun to emerge. Orchardgrass sprout was at 1 leaf, and annual ryegrass was at 1.5 to 2 leaf.

The treatments at this timing were residual preemergent herbicides applied separately or with postemergent components of Goal and metribuzin (Table 3). Three additional applications were made (Table 3). The second set of applications consisted of a residual preemergent herbicide plus the postemergent herbicides Goal and metribuzin and was made on October 17. The third and fourth applications were either a combination of three residual herbicides, Outlook, Dual Magnum and Kerb, or a single application of Alion. These applications were made November 27, 2017 and January 3, 2018. Conditions at the time of application are shown in Table 4.

Table 2. Application conditions, tall fescue, Forest Grove, OR, 2014–2015.

Application date	Oct. 9, 2014	Nov. 20, 2014
Crop growth stage	Multi-tillered	Multi-tillered
Annual ryegrass growth stage	Preemergence	2–4 leaf
Air temperature (°F)	60	45
Soil temperature at 2 inches (°F)	60	42
Relative humidity (%)	90	90
Wind	Calm	Calm
Cloud cover (%)	100	100
First moisture (inches)	Oct. 11 (0.14)	Nov. 20 (0.29)
Soil texture: Woodburn silt loam		

Table 3. Treatments for management of grass weeds in orchardgrass grown for seed, 2017–2018.

Treatment[1]	Rate	Timing[2]
	(lb ai/a)	
Untreated	0	A
Axiom fb	0.55	A
Alion	0.02	D
Zidua fb	0.09	A
Alion	0.02	D
Fierce fb	0.14	A
Alion	0.02	D
Axiom + Goal + metribuzin fb	0.55 + 0.13 + 0.17	A
Outlook + Kerb	0.98 + 0.39	D
Fierce + Goal + metribuzin fb	0.14 + 0.13 + 0.28	A
Outlook + Kerb	0.98 + 0.39	D
Axiom + Goal + metribuzin fb	0.55 + 0.13 + 0.17	B
Outlook + Kerb	0.98 + 0.39	D
Fierce + Goal + metribuzin fb	0.14 + 0.13 + 0.28	B
Outlook + Kerb	0.98 + 0.39	D
Fierce + Goal + metribuzin fb	0.14 + 0.13 + 0.28	B
Outlook + Kerb	0.98 + 0. 39	C
Zidua + Goal + metribuzin fb	0.1 + 0.13 + 0.28	B
Outlook + Kerb	0.98 + 0.39	C
Fierce + Goal + metribuzin fb	0.14 + 0.13+ 0.28	B
Dual Magnum + Kerb	1.27 + 0.39	C

[1]fb = followed by

[2]A = Oct. 6, 2017; B = Oct. 17, 2017; C = Nov. 27, 2017; D = Jan. 3, 2018

Table 4. Application conditions, orchardgrass, Adair, OR, 2017–2018.

Application date	Oct. 6, 2017	Oct. 17, 2017	Nov. 27, 2017	Jan. 3, 2018
Crop growth stage: Multi-tillered				
Annual ryegrass growth stage	1–2 leaf	2–2.5 leaf	2–3 leaf	3 leaf–3 tillers
Air temperature (°F)	52	53	54	40
Soil temperature at 2 inches (°F)	46	50	49	38
Relative humidity (%)	87	87	82	77
Wind (mph, direction)	Calm	0–3 SW	Calm	Calm
Cloud cover (%)	5	80	10	40
First moisture (inches)	Oct. 7 (0.03)	Oct. 19 (0.66)	Nov. 28 (0.35)	Jan. 4, 2018 (0.05)
Soil texture: Amity silt loam				

Results and Discussion

Study 1

A visual evaluation conducted on October 31, 2014 compared herbicide treatments to the untreated area (data not shown). No crop injury was apparent. No treatments were providing greater than 60% control of the seedling flush. An evaluation 2 weeks after the second sequence of treatments (applied on November 20) indicated substantial injury with the treatments containing Rely. Sprout control ratings improved slightly, to 75% in most treatments, with the exception of the Fierce + Nortron + Rely + Sharpen treatment, which improved to 80% (data not shown).

Annual ryegrass control was visually assessed on March 25, 2015 (Table 5). Axiom + Goal followed by Fierce, Fierce + Goal followed by Axiom, and Fierce + diuron were controlling over 90% of the sprout. Rely treatments were controlling the sprout at 98% and above. These same treatments were controlling annual ryegrass at 89–93%.

Visual assessment data show that the postemergent treatments with Rely, in combination with a residual preemergent herbicide, provided the highest level of control of the annual ryegrass. Postemergent treatments are able to kill or severely injure emerged annual ryegrass, depending on growth stage. Combining a preemergent herbicide with a postemergent herbicide inhibits the recovery of partially controlled annual ryegrass. It is possible that the early rainfall prior to the first application triggered germination of a portion of the annual ryegrass population, which was not seen at

Table 5. Crop injury, volunteer crop sprout, annual ryegrass control, and yield following herbicide applications in tall fescue, 2014–2015.

Treatment[1]	Timing[2]	Tall fescue[3]	Volunteer sprout[3]	Annual ryegrass[3]	Clean seed
		(% injury)	---- (% control) ----		(lb/a)
Untreated	A	0	0	0	736
Axiom	A	0	53	50	671
Axiom + diuron	A	0	73	48	840
Axiom + Goal	A	0	78	69	620
Axiom + Goal fb	A	4	91	85	758
Fierce	B				
Fierce	A	0	80	73	722
Fierce + diuron	A	0	93	78	653
Fierce + Goal	A	0	65	70	764
Fierce + Goal fb	A	0	93	79	746
Axiom	B				
Axiom + Goal fb	A	5	98	89	915
Outlook + Rely	B				
Fierce + Goal fb	A	4	100	91	783
Outlook + Rely	B				
Axiom fb	A	13	100	93	783
Fierce + Nortron	B				
+ Rely + Sharpen	B				
LSD (P = 0.05)		5	15	13	400
CV		187	14	13	37

[1]fb = followed by
[2]A = Oct. 9, 2014; B = Nov. 20, 2014
[3]Evaluated March 25, 2015

the first visit to the site. Later flushes of annual ryegrass were controlled to varying degrees by the application of preemergent herbicides, depending on product efficacy.

Yields were not affected by treatments, probably due to the inability to clean the annual ryegrass seed out of the tall fescue seed, making the averages a combination of both species.

Study 2

The second study looked at timings of postemergent treatments in conjunction with treatments of preemergent herbicides (Table 6). The best annual ryegrass control in the orchardgrass study generally occurred when the initial application was made at the second timing and the second application was made at the third timing. It is possible that the earlier application of Kerb had better conditions (wet and cold) than the fourth application, which was followed by a dry, warm spell.

Table 6. Crop injury, annual ryegrass control, and yield in orchardgrass following herbicide treatments, 2017–2018.

Treatment[1]	Timing[2]	Orchardgrass[3]	Annual ryegrass[3]	Clean seed yield
		(% injury)	(% control)	(lb/a)
Untreated	A	0	0	465
Axiom fb	A	4	80	709
Alion	D			
Zidua fb	A	1	76	638
Alion	D			
Fierce fb	A	3	80	588
Alion	D			
Axiom + Goal + metribuzin fb	A	5	83	655
Outlook + Kerb	D			
Fierce + Goal + metribuzin fb	A	6	96	739
Outlook + Kerb	D			
Axiom + Goal + metribuzin fb	B	4	89	752
Outlook + Kerb	D			
Fierce + Goal + metribuzin fb	B	5	95	719
Outlook + Kerb	D			
Axiom + Goal + metribuzin fb	B	0	94	853
Outlook + Kerb	C			
Fierce + Goal + metribuzin fb	B	5	100	662
Outlook + Kerb	C			
Zidua + Goal + metribuzin fb	B	11	98	685
Outlook + Kerb	C			
Fierce + Goal + metribuzin fb	B	5	93	618
Dual Magnum + Kerb	C			
LSD (P = 0.05)		8	14	228
CV		131	12	24

[1]fb = followed by
[2]A = Oct. 6, 2017; B = Oct. 17, 2017; C = Nov. 27, 2017; D = Jan. 3, 2018
[3]Evaluated April 25, 2018

Conclusion

Preemergent herbicides can provide partial control of annual ryegrass contamination in tall fescue and orchardgrass crops, but sequential programs utilizing both preemergent and postemergent herbicides are necessary for more complete control. The postemergent herbicides need to be applied after the annual ryegrass has emerged but before it has developed tillers.

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SPATIAL VARIATION IN ROUGHSTALK BLUEGRASS AFFECTS TALL FESCUE SEED YIELD

G.W. Mueller-Warrant, K.M. Trippe, and W.P. Jessie

Introduction

Roughstalk bluegrass is an especially troublesome weed of grasses grown for seed. Severity of infestations increases over time through establishment of new seedlings and enlargement/spread of older plants. This weed reduces crop yield through competition in the field and increases losses during seed cleaning due to difficulty of removing the hairy weed seed from crops such as tall fescue and perennial ryegrass. Registered herbicide treatments usually control seedling roughstalk bluegrass, but incompatibilities between rainfall patterns, weed seed germination, timing of herbicide applications, and uniformity of stubble, chaff, and weed seed distribution often allow some new seedlings to successfully establish in portions of fields. Use of glufosinate herbicide as a "salvage/rescue treatment" does a good job of reducing seed production by roughstalk bluegrass plants but also reduces tall fescue seed yield. High-resolution mapping of roughstalk bluegrass distribution within tall fescue seed fields was conducted to quantify yield loss due to this weed and to identify patches that might be amenable to semi-automated "spot-spraying" through modern GPS-controlled field sprayers.

Materials and Methods

Tests were conducted in three established stands of tall fescue grown for seed in Linn County, OR. Roughstalk bluegrass severity was first evaluated in January 2018 at grid sample spacing of 180 feet, followed by additional counts at 60-foot resolution later in the winter in the portions of fields transitioning from low to high density of roughstalk bluegrass. The number of roughstalk bluegrass plants encountered in 32 stops along a 64-foot circular path walked around each target point was counted, with a maximum of 5 plants allowed in the 2-square-foot zones viewed at each stop. When totals of 10 or more roughstalk bluegrass plants were found in the circular walk, the count was terminated to speed up the process. Aerial photographs were taken in late spring as a possible alternative means for quantifying weed severity.

The three fields varied in age, ranging from a new stand with only one prior harvest to older stands in production for more than a decade. Fields studied in the first year of the project were from a single grower. Data from the coarser-resolution weed counts were made available to the grower in time for consideration of spatially varying application of herbicides such as glufosinate. However, the unusually high prices being offered for grass seed in 2018 led to a decision to not apply treatments likely to substantially reduce tall fescue seed yield. Hence, the relationship between roughstalk bluegrass severity and combine yield data in 2018 was simply one of competition between crop and weed, rather than a combination of that factor plus injury where "salvage/rescue treatments" might have been applied.

Results and Discussion

At two of the sites, there were no clear relationships between roughstalk bluegrass severity and tall fescue seed yield. In the case of the second-year stand, roughstalk bluegrass plants had simply not yet had the opportunity to grow into sizes able to compete aggressively with the tall fescue, at least not on scales represented by combine yield monitor data points and grid sample measurements of weed severity. The problem at the second site was that moderately high roughstalk bluegrass densities, combined with conversion of the tall fescue stand from rows to varying-sized clumps no longer identifiable by row spacing or direction, resulted in greater variability in the uniformity of tall fescue stands than in the severity of roughstalk bluegrass infestation.

The third site was in its 13th year of seed production in 2018, with easily discernible variation in roughstalk bluegrass infestation severity ranging from nearly weed-free conditions in much of the center and northwest quarter of the field to severe patches on the south side of the field and around much of its periphery. Approximately 40% of the field was characterized as having moderate to heavy infestations of roughstalk bluegrass, defined as at least one roughstalk bluegrass plant present per every 5 square feet of area. Our technique for measuring roughstalk bluegrass severity maxed out at 2.5 plants/ft^2, a severity level actually encountered at several spots across the field.

When ordinary least squares (OLS) regression was used, tall fescue (yield monitor) seed yield was best defined by fourth-degree regressions on roughstalk bluegrass severity, with *R*-square values of 48.7% in 2018 and 27.1% in 2017. Predicted yield loss at average levels of roughstalk bluegrass infestation was 49.1% for 2018 and 20.3% for 2017. Yield loss measurements in 2017 were compounded by the fact that weed severity was measured only in 2018, not in 2017, and by the grower's application of glufosinate to the southwest corner of the field in 2017.

Best practices for spatial data analysis include replacement of OLS regression with geographically weighted regression (GWR) models able to account for the presence of spatial autocorrelation—the tendency of measurements near each other in space to possess similar values simply due to their geographic proximity. When GWR was run on tall fescue yield as a function of roughstalk bluegrass severity, only a cubic polynomial was needed, with *R*-square values of 53.5% in 2018 and 34.9% in 2017. The GWR model allows regression coefficients to vary across the field and therefore lacks the simpler interpretations of the OLS model.

Compared with many other factors commonly used in analysis of spatial data, the impact of roughstalk bluegrass on tall fescue seed yield stands out as an unusually strong factor with clear implications. Because some of the yield monitor signal was actually from roughstalk bluegrass seed harvested along with the tall fescue seed, the true impact of this weed on tall fescue clean seed yield would be even worse than that indicated in these regressions. Separate samples taken from swathed windrows indicated that the grower's combines were removing approximately three-quarters of all roughstalk bluegrass seed initially present in the windrows.

Our next step was to evaluate the potential for aerial photography to supplement or potentially replace the most labor-intensive step in our analysis, the 60-foot grid sampling of roughstalk bluegrass severity. Data taken on behalf of crop advisors working for Nutrien Ag Solutions included color, infrared, and NDVI in photographs taken from a piloted airplane on April 4, 2018. Data contracted by USDA-ARS consisted of color imagery from UAV drone flights on May 30, 2018. Tests of relationships between bands of these images and the 60- to 180-foot grid samples of roughstalk bluegrass severity found strongest links for the May 30 color mosaic band2 and the April 4 color image band3, infrared, and NDVI. Regressing grid sample roughstalk bluegrass severity on values of these four bands plus their squares produced an *R*-square value of 47.0%, a reasonable but far-from-perfect recreation of weed severity even with knowledge of weed density over areas approximately 20 feet wide. In the absence of prior knowledge of weed density, these images would almost certainly do an even poorer job of quantifying roughstalk bluegrass severity across a field.

To test the possibility that the weed severity estimates produced from the aerial photographs were actually better than our grid sample counts and not just randomly different, we regressed combine yield monitor data on the same four image bands plus their squares. The best OLS model for 2017 yield monitor data omitted the NDVI terms and possessed an *R*-square value of 28.9%. The best model for 2018 yield monitor data omitted the linear NDVI term and possessed an *R*-square value of 44.4%. Both of these *R*-square values were poorer than those for the GWR third-degree polynomials for roughstalk bluegrass severity, although the 2017 OLS image band model was slightly better than the OLS roughstalk bluegrass severity model.

The difficulty in making multiple image bands perform as well as actual grid samples in modeling yield monitor data suggests that there will be no easy shortcuts simply from aerial photography conducted at an approximately 1-foot pixel size when subsequently averaged over distances in the range of 60 feet. Some degree of intensive within-field sampling of weed severity currently appears to be unavoidable, although higher-resolution imagery capable of identifying individual roughstalk bluegrass plants and/or leaves might provide an alternative to the 60-foot grid sampling we employed in this study. Movement of leaves in the wind will cause difficulties in obtaining clear images of individual grass plants.

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EVALUATION OF FUNGICIDES FOR ERGOT CONTROL IN KENTUCKY BLUEGRASS SEED PRODUCTION

J.K.S. Dung, Q. Cheng, D.L. Walenta, and K.E. Frost

Introduction

The fungal pathogen *Claviceps purpurea* causes ergot in Kentucky bluegrass seed crops in the Pacific Northwest (Alderman et al., 1998). Ergot is also a major disease problem in perennial ryegrass seed produced in irrigated production regions of Oregon and Washington. Ergot negatively affects the grass seed industry at all stages of production; the disease reduces yield, makes harvest difficult, hinders seed cleaning and certification efforts, and can prevent the sale of seed and seed by-products such as screenings and pellets. The fungus infects the unfertilized flowers of grasses and grains and transforms seed into dormant resting structures called sclerotia that overwinter and produce primary inoculum (ascospores) the next season.

Chemical management of ergot relies on fungicide applications during flowering to protect ovaries from airborne ascospores during pollination. Grass seed growers often make multiple fungicide applications during the flowering period in an effort to prevent and control the disease (Walenta et al., 2016). Fungicides (azoxystrobin and propiconazole) are applied either separately or as one of two commercial products that combine both active ingredients in varying amounts (with or without a third fungicide, benzovindiflupyr). These same active ingredients may also be used for rust and/or powdery mildew control in grass seed crops.

Taking into account the potential for repeated applications of similar fungicides for ergot, powdery mildew, and rust control in grass seed crops, the potential exists for resistance development in these fungal pathogens. A need exists to incorporate new active ingredients into the production system due to the limited fungicide options that are currently available for ergot management. Moreover, the rotation of fungicide chemistries or use of fungicides with multiple modes of action could delay the development of fungicide resistance in pathogens affecting grass seed. The objective of this research is to evaluate the efficacy of novel fungicides and fungicide combinations to control ergot in grass grown for seed.

Materials and Methods

Two fungicide trials were established at the Oregon State University Central Oregon Agricultural Research and Extension Center, in Madras, OR. Separate plots of Kentucky bluegrass cultivars 'Blue Ghost' and 'Shamrock' (26 feet long x 5 feet wide with 3-foot buffers) were seeded (5 lb seed/acre) on August 12, 2016. Plots were artificially infested with *C. purpurea* sclerotia on October 20, 2016. Plots exhibited ergot symptoms and produced sclerotia during the summer of 2017 prior to the establishment of the trial in April 2018. The experimental design was a randomized complete block with four and five replicates for 'Blue Ghost' and 'Shamrock', respectively.

Five fungicide treatments and a nontreated control were compared in both trials, with Quilt Xcel SE used as an industry standard. Fungicides were applied to 'Blue Ghost' and 'Shamrock' plots at the beginning of anthesis (Feekes 10.51) on May 21, 2018 and May 18, 2018, respectively. Applications were made using a CO_2-charged spray boom configured with three TP8002VS flat fan nozzles spaced 18 inches apart and delivering 20 gal/acre at 28 psi.

Samples consisting of 100 seed heads were randomly collected from each plot on July 3, 2018. Ergot incidence and severity were measured based on the proportion of panicles containing sclerotia and the number of sclerotia present in each panicle, respectively. Data were subjected to analysis of variance (ANOVA), and treatment means were compared using Tukey's honest significant difference test ($P < 0.05$).

Results and Discussion

A significant effect of fungicide treatment was observed for ergot incidence and severity in 'Blue Ghost' ($P = 0.0002$) and 'Shamrock' ($P < 0.0001$) (Table 1). Trivapro SE, Quilt Xcel SE, Aproach 2.08 SC, and A19649B significantly reduced ergot incidence and severity in 'Blue Ghost' compared to the control. None of the fungicides was significantly different from the industry standard, Quilt Xcel SE. All of the fungicides significantly reduced ergot incidence and severity in 'Shamrock' compared to the nontreated control. Overall, fungicide treatments reduced ergot incidence up to 28% and ergot severity up to 84% depending on the cultivar. These data can be used to obtain new and/or expanded fungicide labels for disease management in grass seed crops.

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Table. 1. Ergot incidence and severity in two Kentucky bluegrass cultivars following treatments with fungicides during anthesis.[1]

	FRAC group	-------- 'Blue Ghost' --------		-------- 'Shamrock' --------	
Treatment and rate[2]		Incidence[3]	Severity[4]	Incidence[3]	Severity[4]
(oz/a)					
Control	—	0.39 a	148.3 a	0.25 a	56.0 a
Priaxor SC, 6.0	7 + 11	0.28 ab	81.8 ab	0.10 b	16.2 b
A19649B, 3.8	7	0.21 bc	50.5 b	0.09 b	13.8 b
Aproach 2.08 SC, 12.0	11	0.21 bc	51.0 b	0.12 b	17.6 b
Trivapro SE, 27.4	3 + 7 + 11	0.11 c	24.3 b	0.06 b	12.4 b
Quilt Xcel SE, 14.0	3 + 11	0.17 bc	46.0 b	0.10 b	19.6 b
P-value		0.0002	0.0002	< 0.0001	< 0.0001

[1]Column means followed by the same letter are not significantly different at $P < 0.05$ as determined by Tukey's honest significant difference test.
[2]All products were applied with Induce, a nonionic surfactant, at 0.25% v/v.
[3]Ergot incidence = proportion of panicles containing sclerotia, out of 100 panicles sampled per plot
[4]Ergot severity = number of sclerotia present in each panicle, out of 100 panicles sampled per plot

ARE HIGHER YIELDS POSSIBLE IN ANNUAL RYEGRASS SEED CROPS? (YEAR 1)

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

Introduction

Forage grass seed crops, including annual ryegrass (*Lolium multiflorum* L.), are a vital part of seed production enterprises in Oregon. Like other cool-season grasses, annual ryegrass produces only 15–33% of its potential seed yield. Lodging of the crop during flowering is one of the major factors limiting seed yield. Making better use of management practices that reduce stem length and decrease lodging is one area that should be further explored to address seed yield losses.

Seed yield is reduced by lodging during anthesis and early seed fill as a result of self-shading in the canopy and reduction in pollination. While trinexapac-ethyl (TE) has been shown to increase yield in perennial ryegrass, its use patterns and potential effects on the seed yield of annual ryegrass are relatively understudied, especially in Oregon. Previous work in the northern hemisphere suggests that seed yield responses of annual ryegrass to TE are generally small (Mellbye et al., 2007; Rijckaert, 2010; Macháč, 2012). However, new studies conducted in New Zealand report seed yield increases of 30–50% when TE is applied (Trethewey et al., 2016).

In addition to plant growth regulator (PGR) use, defoliation by grazing or mechanical cutting is also used to reduce stem length, decrease lodging, and increase seed yield in annual ryegrass seed crops across the globe. Historically, final defoliation by grazing or mowing is carried out at the appearance of the first node on reproductive stems (BBCH 30–31), although new research has demonstrated higher seed yields when defoliation occurs slightly later (BBCH 32–33) (Rolston et al., 2010). Effects of spring grazing on annual ryegrass seed crops were evaluated in Oregon during the late 1970s (Young et al., 1996), but no work has been done since the introduction of PGRs.

Recent research shows that even greater seed yield increases in annual ryegrass crops are possible when TE applications are strategically timed with spring defoliation. For example, Rolston et al. (2012) reported seed yields of 3,015 lb/acre when 200 g ai TE/ha was applied to annual ryegrass that had been defoliated at BBCH 32–33. This represents a 35% increase over the treatment with the same TE rate applied to annual ryegrass defoliated once at BBCH 30–31 and a 123% increase over the zero TE treatment. This response to TE and later-timed defoliation was related to delayed lodging and better light interception by the standing crop.

Current prices of TE are relatively low, and many annual ryegrass growers are accustomed to grazing fields. If we could better understand how these two lodging reduction strategies can best work together in the Oregon environment, there is strong potential for economic benefit to the grower. The objectives of this work are to define optimum treatment applications of TE across multiple defoliation timings for annual ryegrass seed crops and to determine whether interaction between TE and defoliation will further reduce lodging and increase seed yield.

Materials and Methods

A field trial with Oregon ‘Gulf’ and New Zealand ‘Winterstar II’ annual ryegrass varieties was established in September 2017 at OSU’s Hyslop Research Farm. The experimental design for the trial is a randomized complete block with a split-plot arrangement of treatments and three replications. Plot size is 11 feet x 45 feet. Plots were established with conventional tillage during fall. Spring nitrogen (N) was applied as urea (46-0-0) at 130 lb N/acre. Routine herbicide sprays were applied to manage weeds as needed. Defoliation by grazing was simulated using a flail mower. The experimental design was a randomized complete block with a split-plot arrangement of treatments and four replications. Main plots were defoliation timings, and subplots were TE rate. Subplots were randomly allocated within defoliation main plots.

Defoliation main plots included the following timings:

- Untreated control (no defoliation)
- Single cutting at BBCH growth stage 31 (appearance of first node)
- Triple cutting: at BBCH growth stage 31 and twice when regrowth was at BBCH 32–33

TE subplots included the following application rates and timings

- Untreated control (no PGR)
- Trinexapac-ethyl (Palisade EC): 1.4 pt/acre at BBCH 32
- Trinexapac-ethyl: 2.8 pt/acre at BBCH 32
- Trinexapac-ethyl: 4.2 pt/acre at BBCH 32

Defoliation by flail mowing occurred on March 19, 2018 for the single cutting and on March 19, April 2, and April 13, 2018 for the triple cutting. The TE treatments were applied at the two-node stage (BBCH 32) 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 annual ryegrass plot near crop maturity, and dry weight was determined. The crop height of annual ryegrass was also measured for each treatment at harvest maturity. Lodging ratings were recorded weekly from the start of anthesis until harvest.

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

Both the single- and triple-mow treatments significantly increased seed yield in 'Gulf' (Table 1), but there were no effects of mowing 'Winterstar II' annual ryegrass (Table 2). Maximum seed yield with 'Gulf' was attained with a single mowing, which resulted in a 74.5% seed yield increase (Table 1). There was no advantage or disadvantage to the triple-mow over the single-mow treatment. Both mowing treatments also increased seed number and HI and decreased percent cleanout, biomass, fertile tiller length, and spike length.

Seed yield was also significantly increased by PGR treatments for both varieties (Tables 1 and 2). Maximum seed yield was attained with the 4.2 pt TE/acre rate applied at BBCH 32 (two-node stage), although there were also significant increases at lower treatment rates. All PGR treatments increased seed number and HI, while decreasing thousand-seed weight, tiller length, and spike length in both varieties. There were no PGR effects on biomass.

An interaction of spring mowing and PGR for seed yield and seed number was evident in 'Gulf' but not in 'Winterstar II'.

Conclusion

The results of this work indicate that a combination of spring mowing (single or triple) combined with at least 2.8 to 4.2 pt TE/acre can increase seed yield by as much as 173%. It is noted that overall seed yields were low in this trial. This work will be repeated in the 2018–2019 crop season.

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Table 1. Interaction of spring mowing and plant growth regulators (PGRs) on seed yield, yield components, and growth characteristics of Oregon 'Gulf' annual ryegrass.

TE treatment	Mowing treatment	Yield[1]	Cleanout	Seed weight	Fertile tillers	Tiller length	Biomass	Seed no.	Harvest index
		(lb/a)	(%)	(g)	(no./ft^2)	(cm)	(kg/ha)	(no./m^2)	(%)
Untreated	0x	693 a	11.9	3.176	52.5	150.0	12,806	24,693	6.38
1.4 pt/a	0x	736 a	12.7	3.027	78.5	149.2	16,835	27,339	4.85
2.8 pt/a	0x	950 a	11.7	2.854	70.5	137.3	14,994	37,703	7.45
4.2 pt/a	0x	1,414 bc	10.8	2.753	86.8	127.8	18,035	58,167	9.58
Untreated	1x	1,108 ab	9.9	3.017	84.3	125.2	10,947	41,647	11.73
1.4 pt/a	1x	1,450 bc	8.8	2.841	88.0	110.8	11,181	57,153	16.23
2.8 pt/a	1x	1,892 de	9.1	2.747	78.3	105.2	10,629	77,181	23.05
4.2 pt/a	1x	2,169 e	9.0	2.741	84.5	100.0	10,699	88,832	24.28
Untreated	3x	873 a	11.4	2.840	82.5	114.6	8,818	34,577	11.63
1.4 pt/a	3x	1,683 cd	9.9	2.641	90.8	104.6	9,308	71,435	21.38
2.8 pt/a	3x	1,978 de	9.3	2.611	108.5	95.9	10,605	84,895	23.65
4.2 pt/a	3x	2,185 e	9.9	2.591	101.8	90.2	9,023	94,591	29.77

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

Table 2. Interaction of spring mowing and plant growth regulators (PGRs) on seed yield, yield components, and growth characteristics of New Zealand 'Winterstar II' annual ryegrass.

TE treatment	Mowing treatment	Yield	Cleanout	Seed weight	Fertile tillers	Tiller length	Biomass	Seed no.	Harvest index
		(lb/a)	(%)	(g)	(no./ft^2)	(cm)	(kg/ha)	(no./m^2)	(%)
Untreated	0x	660	8.2	4.545	53.0	136.1	16,867	16,281	6.38
1.4 pt/a	0x	875	5.7	4.412	74.8	144.0	16,146	22,220	4.85
2.8 pt/a	0x	1,060	5.8	4.232	71.0	116.1	14,946	28,054	7.45
4.2 pt/a	0x	1,550	5.1	4.061	84.0	120.8	16,189	42,936	9.58
Untreated	1x	691	8.1	3.967	37.3	121.5	7,575	19,537	11.73
1.4 pt/a	1x	1,140	7.2	3.633	67.0	107.2	9,728	35,411	16.23
2.8 pt/a	1x	1,378	8.2	3.601	70.5	102.2	10,880	42,862	23.05
4.2 pt/a	1x	1,649	7.1	3.500	68.8	96.1	9,542	52,905	24.28
Untreated	3x	868	7.3	3.982	59.0	106.3	7,387	24,423	11.63
1.4 pt/a	3x	1,251	5.6	3.794	85.0	98.7	9,152	36,859	21.38
2.8 pt/a	3x	1,725	5.3	3.608	84.8	91.1	8,743	53,692	23.65
4.2 pt/a	3x	1,885	7.5	3.648	83.5	85.2	7,785	57,915	29.77

THE EFFECT OF SEED AGE ON THE GERMINATION, DORMANCY, AND FIELD EMERGENCE OF ANNUAL RYEGRASS USED AS A COVER CROP

M.E. Mellbye, D.L. Towery, D.M. Perkins, W.P. Jessie, and S.G. Elias

Introduction

Annual ryegrass is an accepted cover crop in parts of the midwestern United States for corn and soybean production. Cover crops help prevent soil erosion, improve soil tilth, increase soil organic matter, and capture nutrients subject to leaching or runoff losses. Annual ryegrass used as a cover crop is characterized by quick establishment in overseeding, drilling, and broadcast applications if temperature and moisture conditions are favorable. In addition, annual ryegrass is especially noteworthy for developing a deep root system that helps improve the rooting depth of subsequent corn or soybean crops (Plumer et al., 2017).

When used as a cover crop in the Midwest, annual ryegrass is occasionally observed growing in fields a year or more after the original seeds were planted. Midwestern farmers have questioned whether this is due to the presence of dormant or “latent” seed in a newly harvested crop, which is a form of primary dormancy referred to as “postharvest dormancy.” Primary dormancy is the condition wherein newly harvested, viable seeds fail to germinate in the presence of suitable conditions. In contrast, secondary dormancy occurs when viable seed fails to germinate because of unsuitable conditions such as drought or extreme high or low temperatures. When the environment becomes favorable again, seeds resume germination. This phenomenon is not unique to annual ryegrass; it occurs in many types of seeds as a survival mechanism under adverse conditions.

In the Midwest, farmers have asked whether storing seed would affect dormancy and stand establishment. The objectives of this study were to: (1) determine whether there is a difference in seed dormancy between newly harvested annual ryegrass seed and seed that has been stored for 1 year, and (2) evaluate whether the age of seed has an effect on emergence under field conditions in Oregon and in the Midwest.

Materials and Methods

Two trials were conducted in this study, one under growth chamber conditions in the OSU Seed Laboratory and the other under field conditions in Oregon and Indiana. In both experiments, seed from the same four annual ryegrass varieties (‘Bounty’, ‘KB Royal’, ‘Ed’, and ‘Gulf’) were used. Varieties were from different seed companies and were selected to represent a range of annual ryegrass varieties produced in Oregon. The variety ‘Gulf’ is the oldest and one of the most commonly grown annual ryegrass varieties in Oregon, but it lacks sufficient cold tolerance for use in the Midwest. ‘Bounty’, ‘KB Royal’, and ‘Ed’ are among varieties with improved cold tolerance that have been developed for use in the Midwest (Mellbye, 2017).

A total of eight seed lots were sampled in Oregon, four from 2017 (new crop) and four of the same varieties from 2016 (1-year-old seed stored in Oregon). Samples were collected from seed lots that had gone through commercial seed conditioning in approved Oregon seed cleaning warehouses. Seed samples were obtained using standard sampling procedures used in the seed industry and by the OSU Seed Certification Service, which are designed to obtain representative and unbiased samples. A minimum of 30 bags were probed (or 1 bag/1,000 lb seed) with a sampling tier to obtain a sample size of approximately 2 lb of seed.

Seed germination tests

In the first experiment, seed germination was measured on new-crop (2017) and 1-year-old seed (2016) for each variety. Germination tests were carried out by the OSU Seed Laboratory according to AOSA rules for testing seeds (AOSA, 2017). All germination tests were conducted with and without a 7-day prechilling treatment at 10°C. The prechilling treatment is a common method for breaking postharvest dormancy in grass seed crops.

To evaluate the effect of storage time on dormancy and seed viability, especially of new-crop seed, the germination tests were conducted over a period of time. The first testing date was in early postharvest of the new crop (August 1, 2017). The second test was conducted 2 months postharvest of the new crop (October 1, 2017), and the final testing date was approximately 8 months postharvest (April 20, 2018). For the 1-year-old crop, the testing dates corresponded to 12, 14, and 20 months postharvest.

Field emergence

In the second experiment, the same four varieties (eight seed lots) were planted in small plots in Oregon and Indiana to evaluate emergence under field conditions. Seeds used in these plots were taken from the same samples used in the seed laboratory germination tests, but they did not receive a prechilling treatment. For each field site, 100 seeds of each variety were counted and placed in sealed envelopes. Samples were replicated three times for each site and included a check plot with no seed planted. The plot areas were defined by a 2-inch x 4-inch wooden frame anchored to the ground and laid out in an 8-foot x 5-foot grid in a completely randomized block design with three replications. Individual plots within each replication were separated by 1-inch x 2-inch lumber and were 1 ft^2 in size. The wooden grid was used to ensure plot separation and to aid in later evaluations.

Three locations were used in the field emergence experiment: one in Oregon and two in Indiana. The Oregon location (Lebanon, OR) was managed to represent optimal seed bed conditions. The site was cultivated, raked, and packed to prepare a smooth, firm, sod-free seedbed. It was watered three times in late August and early September with overhead irrigation (0.5 inch per set) to allow volunteer ryegrass and weeds to be controlled with glyphosate prior to planting on September 20, 2017. Seed was raked in and packed to ensure good seed–soil contact, then irrigated five times (0.4 inch per set) over a 2-week period to ensure that moisture was not a limiting factor for germination.

Two fields were selected in Indiana (one near Lafayette, IN and one near Brook, IN) that were in no-till corn and soybean rotations. These sites represented typical or "real-world" conditions found in Midwest agriculture, where seeds are often broadcast and fall cover crop plantings rely on rain for establishment. The annual ryegrass seed plots near Lafayette were broadcast on September 23, 2017 into a silt loam soil with 3% organic matter in dry soil conditions. The first rain occurred approximately 2 weeks later. The Brook site was a level silt loam soil with 4% organic matter. Annual ryegrass seed was broadcast, then lightly raked in and watered with overhead irrigation (0.5 inch per set) every 7 days until emergence. On both the Oregon and Indiana sites, soil temperatures were in the range considered ideal for annual ryegrass germination (65–80°F).

After the annual ryegrass seed germinated in the field plots, seedling emergence was counted at the one- to three-leaf stage in mid-October. In the spring, the ryegrass was controlled with glyphosate in Oregon (2 lb ai/acre applied twice in May). In Indiana, plots were sprayed during farming operations using glyphosate (1.25 lb ai/acre) consistent with Purdue University Extension Service recommendations (Legleiter et al., 2015). A second count of seedling emergence was conducted in the spring and early summer of 2018, followed by a final count in the fall of 2018 to determine whether seed remained viable 1 year after planting.

Results and Discussion

Seed germination

The germination in the seed laboratory of the four annual ryegrass varieties used in the study exceeded 95% when the 7-day prechilling treatment was applied (Table 1). This was true for both years of production and was well above the minimum germination standard of 85% for certified annual ryegrass in the OSU Seed Certification Standards. Even without the prechilling treatment, newly harvested seeds tested 2 and 8 months after harvest and all 1-year-old crop seeds had germination levels that exceeded the OSU certification standard. The germination rates for these lots ranged from 96% to 98%. This was an indication of excellent seed viability and minimal primary dormancy levels for all varieties across both years of production and is typical of seed quality of annual ryegrass grown in Oregon.

Statistical analysis of germination data from the OSU Seed Laboratory indicated that the prechilling treatment and date of the germination test significantly affected germination, while year of production and variety were not significant. Only the new crop seed tested early postharvest (Aug. 1, 2017) showed a benefit to the 7-day prechilling treatment (Table 1). Without prechilling, the newly harvested seed averaged 86% germination. The interaction between varieties and prechilling treatment was not significant, indicating that varieties responded similarly to the prechilling treatment. Likewise, the interaction between varieties and germination dates was not significant, indicating that the response of varieties to the three germination dates was similar.

While not significant, varieties showed some variation in germination, ranging from 78% to 92% (Figure 1). After the early postharvest testing date, however, the four varieties averaged over both years had similar germination levels (Figure 2). The 7-day

Table 1. Mean germination of four annual ryegrass seed varieties (‘Bounty’, ‘KB Royal’, ‘Ed’, and ‘Gulf’) as a function of time after harvest and year of production (new crop versus 1-year-old seed).

Treatment	Year harvested	Prechill (7 days)	Germination[1,2]		
			Aug. 1, 2017	Oct. 1, 2017	Apr. 20, 2018
			(%)		
			(Postharvest)	(2 months postharvest)	(8 months postharvest)
New crop seed	2017	Yes	96	98	97
		No	86	97	97
			(12 months postharvest)	(14 months postharvest)	(20 months postharvest)
1-year-old crop seed	2016	Yes	97	97	97
		No	96	97	96
LSD (0.05)			5	NS	NS

[1]Seed germination tests were conducted at the Oregon State University Seed Laboratory according to AOSA rules.
[2]NS = not statistically significant

prechilling treatment is the standard procedure used by the OSU Seed Lab to break postharvest dormancy (primary dormancy). Previous research documented that this type of dormancy in annual ryegrass is short lived (Elias and Garay, 2012). Approximately 2 months after harvest, dormancy naturally disappears, and the OSU Seed Lab stops prechilling annual ryegrass in early September.

The results of the germination tests confirm that postharvest dormancy is short lived in the annual ryegrass varieties used in this study, which includes varieties that have been used successfully as cover crops in the Midwest. The results also show that there is some dormant seed in newly harvested annual ryegrass; however, the fraction of seed actually dormant was small, as indicated by the comparatively high germination levels present without a prechilling treatment. If planting in the Midwest in September, most of the primary seed dormancy would be broken.

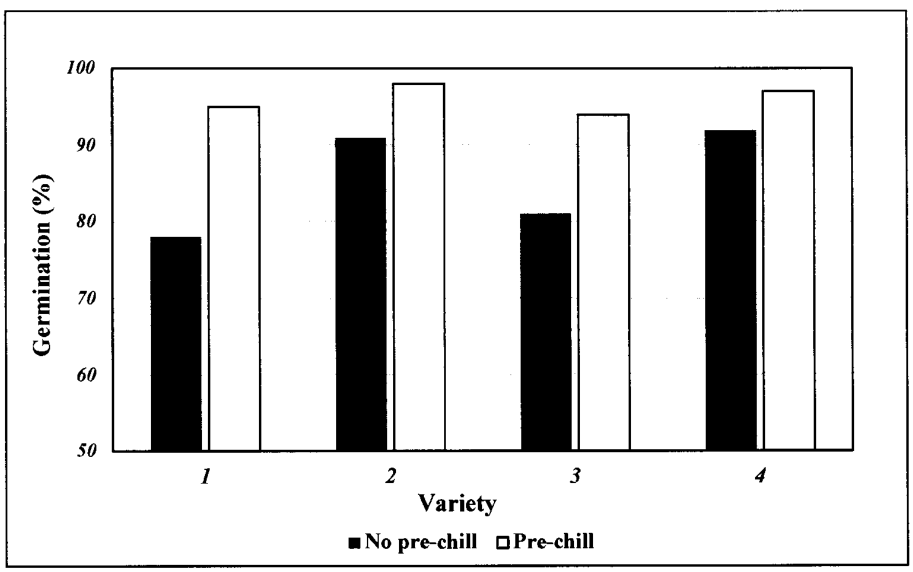

Figure 1. Standard germination test results of four ryegrass varieties tested immediately after harvest with and without prechilling treatment at 10°C for 7 days (2017). Data represent means of four replications; replication data are not available.

Field emergence

Under field conditions, the germination and emergence of annual ryegrass in the Indiana and Oregon field plots was not affected by the year seed was produced (Table 2). At the time of planting in September, seeds of all eight lots had laboratory germination counts at or above 95%. There was no advantage to using seed that had been stored for 1 year before planting.

All four varieties had similar field emergence levels within each site (Table 2). As expected, emergence in the irrigated Oregon plots was greater than on the two Indiana sites that were broadcast and rain-fed or received less water. Mean seedling stand counts per plot in Indiana, averaged across varieties, were 24 in the rain-fed broadcast site and 46 at the site that was irrigated, compared to 84 under optimal conditions in Oregon. Average emergence in Indiana was less than half that observed in Oregon. In Indiana, seed was broadcast over plant residue, resulting in a larger proportion of the seed lacking good seed–soil contact. Thus, there was potential for ungerminated seed to persist into the following year.

The annual ryegrass plantings in both states were allowed to overwinter and then were either sprayed out in early spring with glyphosate following recommended practices (Oregon) or during normal cropping practices for corn production (Indiana) (Plumer et al., 2017). In the Indiana plots, no ryegrass seedlings or established plants were observed in the spring postspray (May–June 2018) or in the fall 1 year after the original seed was planted (October–November 2018). In Oregon, some ryegrass seedlings

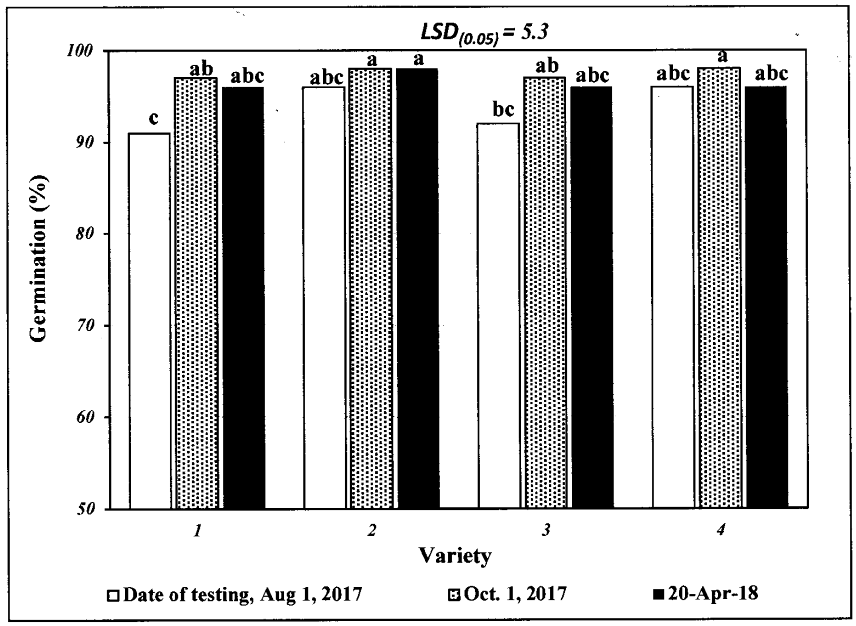

Figure 2. Standard germination test results of four ryegrass varieties tested three times: August 1, 2017, October 1, 2017, and April 20, 2018 (2-year average). Means sharing the same letter do not differ significantly at $P \leq 0.05$.

Table 2. Mean emergence of four annual ryegrass seed varieties ('Bounty', 'KB Royal', 'Ed', and 'Gulf') from two different years of seed production, planted in Oregon and Indiana in the fall of 2017.

Treatment	Year harvested	Seedling emergence in field plots after planting in 2017[1,2]		
		Lebanon, OR Seeded Sep. 20 Cultivated Seed raked in Sprinkle irrigated (Oct. 18, 2017)	Lafayette, IN Seeded Sep. 23 Dry soil No-till broadcast Rain-fed site (Oct. 13, 2017)	NW of Lafayette, IN Seeded Sep. 23 No-till broadcast Overhead irrigated (Oct. 13, 2017)
		---------------------------	(no./plot)	---------------------------
New crop seed	2017	84	26	46
1-year-old crop seed	2016	84	24	39
LSD (0.05)		NS	NS	NS

[1]One hundred seeds were planted in each plot. The Indiana location received 1.1 inch of rain in September, 0.11 inch on October 4, and 0.22 inch on October 6.

[2]NS = not statistically significant

were observed 1 year after planting, but the grass counts were low and were not significantly different from unseeded check plots.

Field conditions and weather patterns in Midwest agriculture vary greatly from year to year, and rainfall patterns in the fall can vary significantly from site to site. In addition, dormant seed that germinated later on the Midwest sites could have been controlled in the normal crop rotation. Predation by animals and winter kill of later-germinated seed could also be a factor. All of these factors may have contributed to the lack of ryegrass seedlings observed 1 year after planting in Indiana.

Conclusion

The observation in the Midwest that annual ryegrass persists in some fields is due to secondary dormancy rather than postharvest (primary) dormancy. Storage of annual ryegrass seed prior to planting is not necessary to achieve good germination in the field. There was no difference in stand counts between newly harvested and 1-year-old seed in Oregon or Indiana. Local environmental conditions and seeding method had more impact on germination and stand establishment of annual ryegrass than age of the seed.

The four varieties used in this study and most other annual ryegrass varieties grown in Oregon have high seed quality, due to the favorable climate for seed development, harvest, and storage. However, not all annual ryegrass varieties are acceptable for use as a cover crop for corn and soybean production in the Midwest. Characteristics such as cold tolerance, enhanced rooting depth, uniform growth in the spring to aid in termination, and ability to control with labeled herbicides are important. We recommend that farmers in the Midwest use annual ryegrass varieties that have been selected for cold tolerance and tested successfully in the region of use.

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

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. Making better use of nitrogen (N) and plant growth regulators (PGRs) is a way to achieve increased yield. In comparison with tall fescue and perennial ryegrass, seed yield response to spring N and PGRs in orchardgrass is relatively understudied.

Since lodging is exacerbated in the high-N 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 (Doerge et al., 2000) for orchardgrass seed crops 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 to (1) measure the effects of multiple N fertilizer rates in the presence and absence of trinexapac-ethyl (TE) and TE + chlormequat chloride (CCC) PGRs, and (2) define optimal treatment and timing of applications of TE and TE + CCC PGR combinations for orchardgrass seed crops.

The first-year results of this study indicate that a combination of spring-applied N and PGRs can increase orchardgrass seed yield in western Oregon conditions (Anderson et al., 2018). Maximum seed yield was attained with 100 lb N/acre, and there was no additional benefit from higher N rates. Seed yield was also significantly increased (by 55%) by TE and TE + CCC PGR treatments. An interaction of spring-applied N and PGR for seed yield was evident in this first-year study. One interesting finding is that, despite this positive interaction, seed yield was enhanced by PGRs even when no spring N was applied.

Materials and Methods

A field trial with ‘Persist’ orchardgrass was established in October 2015 at OSU’s Hyslop Research Farm. The experimental design for the trial is a randomized complete block with a split-plot arrangement of treatments and three replications. Plot size is 11 feet x 38 feet. Fungicide and insecticide treatments are applied to manage pests as needed. During 2015–2017, fall N was applied to all plots at a rate of 40 lb N/acre. The second harvest was taken in 2018. Nitrogen was applied to the main plots in the spring at the following rates:

- 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 (two nodes)
- 1.5 pt/acre TE applied at BBCH 51 (panicles 10% emerged)
- 0.75 pt/acre TE + 1.34 lb/acre CCC at BBCH 32 (two nodes)

Nitrogen was applied on February 9, 2018 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.

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 second-year orchardgrass, in comparison with the untreated control (Table 1). Similar to the first-year study, 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 but had no effect on percent cleanout, seed weight, fertile tiller number, biomass, or HI. Total tissue N concentration did not increase when rates above 100 lb/N acre were applied (data not shown).

Seed yield was also significantly increased (37%) by PGR treatments (Table 2). Unlike the first year of this study, PGR application at the two-node stage (BBCH 32), with both TE and the TE + CCC mixture, resulted in significantly increased seed yields and HI compared to TE applied when panicles were 10% emerged (BBCH 51). All PGR treatments increased seed number and decreased tiller height, but there were no effects on seed weight, biomass, or fertile tiller number.

An interaction of spring-applied N and PGR for seed yield was not evident in this second-year study. Spring N and PGRs enhanced seed yield independently of one another. This work will be repeated in 2019 to examine the effects of these treatments on a second-year stand.

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

N treatment	Yield	Cleanout	Seed weight	Seed no.	Biomass	Fertile tillers	Tiller height	Harvest index
(lb/a)	(lb/a)	(%)	(mg/seed)	(no./m^2)	(kg/ha)	(no./ft^2)	(cm)	(%)
0	570 a	16.6	0.911	70,144 a	16,702	82.5	111	4.0
100	793 b	14.1	0.912	97,714 b	26,381	100.0	117	3.7
140	772 b	14.7	0.915	94,390 b	23,970	93.4	110	3.9
180	779 b	13.9	0.907	96,592 b	24,185	95.3	113	3.8

[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 second-year orchardgrass.[1]

PGR treatment	Yield	Cleanout	Seed weight	Seed no.	Biomass	Fertile tillers	Tiller height	Harvest index
	(lb/a)	(%)	(mg/seed)	(no./m^2)	(kg/ha)	(no./ft^2)	(cm)	(%)
Control (no PGR)	572 a	14.3	0.908	70,664 a	22,117	96.3	129 a	3.2 a
Palisade 1.5 pt/a (BBCH 32)	792 c	15.0	0.919	96,683 bc	22,160	90.0	109 c	4.3 b
Palisade 1.5 pt/a (BBCH 51)	747 b	15.0	0.914	91,415 b	25,291	95.8	115 b	3.5 a
Palisade 0.75 pt/a + CCC 1.34 lb ai/a (BBCH 32)	804 c	15.0	0.902	100,109 c	21,669	80.0	101 d	4.4 b

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

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

T.M. 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. While there are several reasons for low seed yield in tall fescue, lodging of the crop during flowering is a major contributing factor. Chastain et al. (2015) found that applications of trinexapac-ethyl (TE) increased tall fescue seed yield up to 40% over the untreated control and consistently reduced lodging.

There has been no previous research conducted in Oregon to indicate whether a combination of plant growth regulators (PGRs) will affect seed yield in tall fescue. Studies conducted in New Zealand with PGR combinations showed increases of up to 95% in perennial ryegrass seed yield (Chynoweth et al., 2014) and up to 86% in orchardgrass seed yield (Rolston et al., 2014). In New Zealand, forage-type cultivars make up a majority of the perennial ryegrass and tall fescue seed crops. In Oregon, those same species of 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 panicle 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 compared two cultivars: ‘Fawn’ for the forage type and ‘Spyder’ for the turf type. ‘Fawn’ was chosen as the forage type due to its long production history (since 1964), and ‘Spyder’ was chosen as the turf type for its compact growth and ideal turf characteristics. Field trials were conducted at OSU’s Hyslop Farm near Corvallis, OR, during the growing seasons of 2017 and 2018. Soil type at the site was Woodburn silt loam. The study design was a randomized complete block with a split-plot arrangement of treatments and four replications. Main plots were cultivars, and subplots were PGR treatments.

Plant growth regulators applied in this study included TE as Palisade and chlormequat chloride (CCC) as Cycocel. These stem-shortening PGRs were chosen because each acts at a different location in the gibberellin (GA) biosynthesis pathway (Rademacher, 2015). CCC is an onium-type compound and is not currently registered for use in Oregon grass seed crops. TE is an acylcyclohexanedione and is commonly applied in Oregon tall fescue seed crops for lodging control. Treatments evaluated in the study included:

- Untreated control
- 1.5 pt/acre TE (1X rate)
- 1.34 lb ai/acre CCC (1X rate)
- 0.75 pt/acre TE + 0.67 lb ai/acre CCC (½X + ½X)
- 1.5 pt/acre TE + 1.34 lb ai/acre CCC (1X + 1X)
- 1.5 pt/acre TE + 0.67 lb ai/acre CCC (1X + ½X)
- 0.75 pt/acre TE + 1.34 lb ai/acre CCC (½X + 1X)

PGRs were applied at BBCH 32 (two-node stage) with a bicycle-type boom sprayer. Biomass and plant height measurements were taken near peak anthesis (BBCH 65). Assessment of lodging was done during early to late anthesis (BBCH 60–69).

Results and Discussion

‘Fawn’ and ‘Spyder’ both experienced lodging in 2017 (Figure 1). TE applied as a stand-alone treatment provided significant control of lodging in both cultivars, while CCC alone did not (Figure 1). Lodging in ‘Fawn’ had already begun prior to the first measurement. Combinations with ½X TE were less effective in lodging control than those with 1X TE in both cultivars in 2017 (Figure 1) and in ‘Fawn’ in 2018 (Figure 2). Only the untreated control and the CCC alone treatment experienced lodging in ‘Spyder’ in 2018 (Figure 2).

Results of the Bartlett’s test indicated that data could not be pooled across years. Each year’s production results are presented separately. Seed yield was greater in ‘Spyder’ than in ‘Fawn’ in both years (Table 1 and Figure 3). In 2017 and 2018, CCC alone did not increase seed yields in ‘Spyder’ or ‘Fawn’ over the untreated control. An interaction of cultivar and PGR treatment was observed for tall fescue seed yield in 2018 (Figure 3) but not in 2017. Combinations of ½X TE + ½X CCC and 1X TE + 1X CCC increased seed yield in 'Spyder' over the untreated control and either TE or CCC alone. Seed yields in the untreated control were not different than TE or CCC alone in 'Spyder' in 2018.

None of the TE and CCC combinations increased seed yield in 'Fawn' over TE alone (Figure 3). The seed yield in 'Fawn' was determined solely by the rate of TE, with the highest yields observed with 1X TE and intermediate yields observed with the ½X TE rate. The lowest seed yields in 'Fawn' were seen in the untreated control and CCC stand-alone treatment. Seed yield responses in both cultivars were largely attributable to the effects of PGR treatments on reducing lodging and resultant seed number increases from better pollination and improved seed set.

Seed number was higher in 'Spyder' than in 'Fawn' in both years (data not shown). The largest increases in seed number were observed with 1X TE + ½X CCC in 2017 and with 1X TE + 1X CCC in 2018. These treatments also had high seed yields. Seed weight was greater in 'Fawn' than in 'Spyder' (data not shown). In 2017, there was no difference in seed weight among PGR applications. The highest seed weight was observed with the 1X TE + 1X CCC rate in 2018.

Tiller height was reduced by TE alone but not by CCC alone in both 'Spyder' and 'Fawn' (data not shown). The greatest reduction in tiller height was observed with the 1X TE + 1X CCC treatment in 2017 and 2018. The forage type 'Fawn' produced 22% and 27% more biomass than the turf-type 'Spyder' in 2017 and 2018, respectively.

Conclusion

Results from this study indicate that PGR combinations may increase seed yield of tall fescue in western Oregon. TE + CCC combinations and CCC stand-alone treatments did not provide consistent seed yield increases, suggesting that increased seed yields are likely due to application of TE. Application of the 1X rate of TE (1.5 pt/acre) resulted in consistent seed yield increases. Results of this study do not support CCC as a viable PGR option for tall fescue seed production in Oregon, and efforts to register CCC may not be necessary unless additional research reveals such utility.

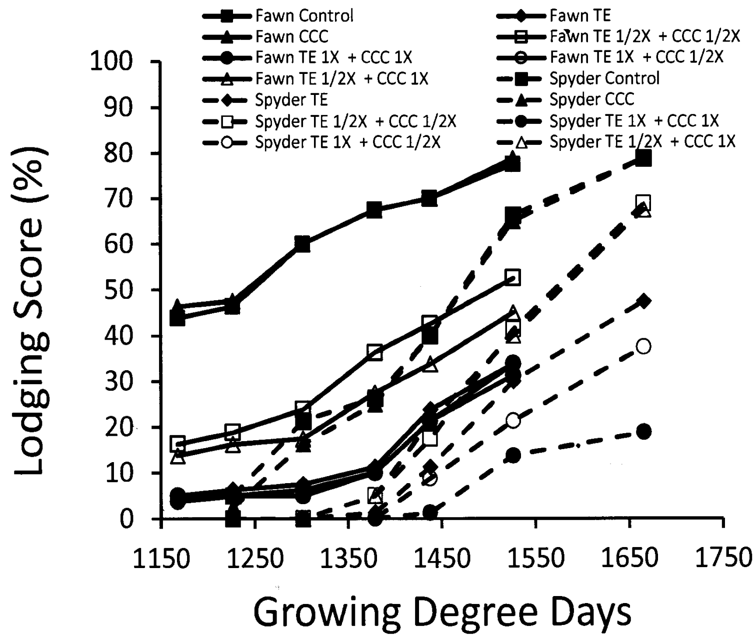

Figure 1. Effect of PGRs and PGR combinations on lodging in 'Spyder' (dashed lines) and 'Fawn' (solid lines), spring 2017. TE 1X = 1.5 pt/a; TE ½X = 0.75 pt/a; CCC 1X = 1.34 lb ai/a; CCC ½X = 0.67 lb ai/a.

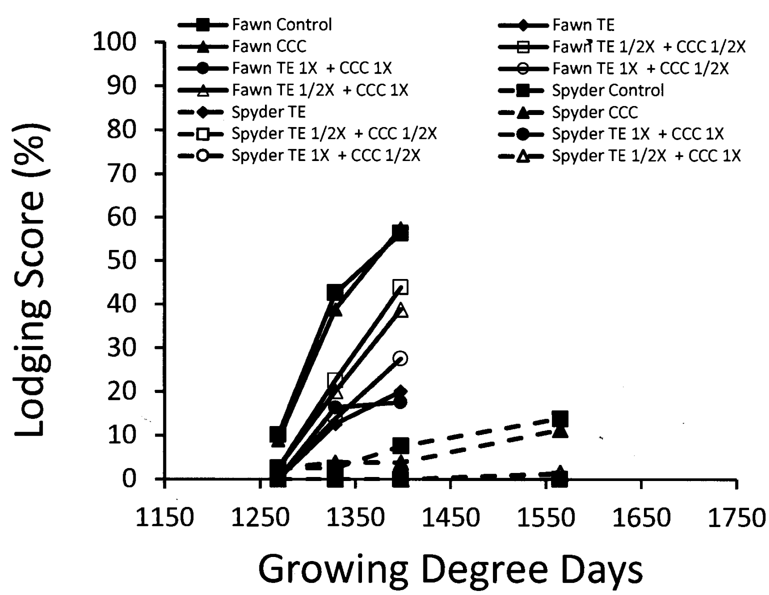

Figure 2. Effect of PGRs and PGR combinations on lodging in 'Spyder' (dashed lines) and 'Fawn' (solid lines), spring 2018. TE 1X = 1.5 pt/a; TE ½X = 0.75 pt/a; CCC 1X = 1.34 lb ai/a; CCC ½X = 0.67 lb ai/a.

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Table 1. Effects of cultivar and PGR combination treatments on seed yield in tall fescue, 2017.

Cultivar	Seed yield[1]
	(lb/a)
Fawn	917 b
Spyder	1,634 a
PGR combination[2]	
Control	1,111 d
1.5 pt/a TE	1,319 b
1.34 lb ai/a CCC	1,174 cd
0.75 pt/a TE + 0.67 lb ai/a CCC	1,256 bc
1.5 pt/a TE + 1.34 lb ai/a CCC	1,394 ab
1.5 pt/a TE + 0.67 lb ai/a CCC	1,505 a
0.75 pt/a TE + 1.34 lb ai/a CCC	1,170 cd

[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

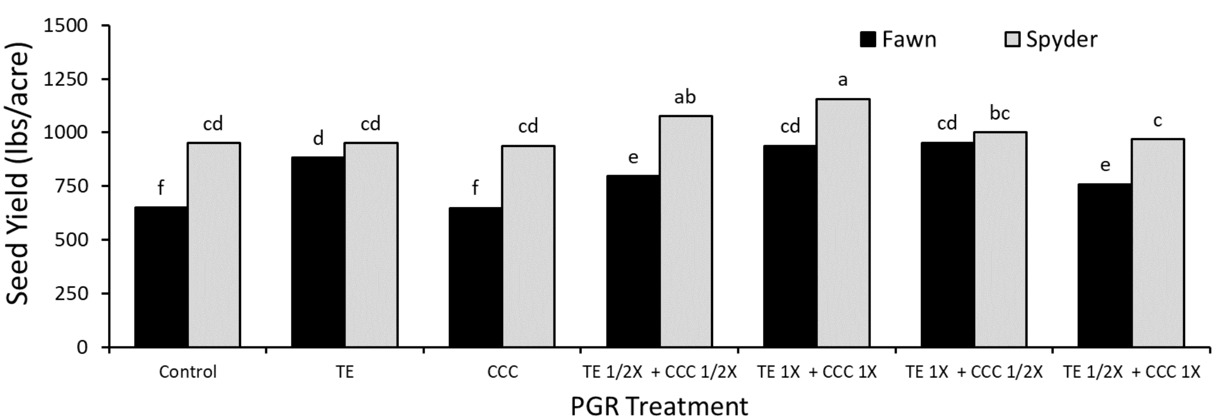

Figure 3. Interaction of cultivar and PGR treatment on seed yield of tall fescue, 2018. Means followed by the same letter are not different by Fisher's protected LSD values (P = 0.05). TE 1X = 1.5 pt/a; TE ½X = 0.75 pt/a; CCC 1X = 1.34 lb ai/a; CCC ½X = 0.67 lb ai/a.

CAN PORTABLE NIR BE USED FOR SEED MOISTURE TESTING IN GRASS SEED CROPS?

T.G. Chastain and N.P. Anderson

Introduction

Seed moisture content is the most reliable indicator of seed maturity and harvest timing in grass seed crops. Swathing within the correct range of seed moisture content will maximize harvestable seed yield and minimize seed loss due to shattering during harvest (Silberstein et al., 2010). Taking an accurate measurement of seed moisture content is a key part of economic management of grass seed crops.

Since pollination and seed maturation are not uniform processes in grass seed crops, a range of seed maturity can be found in a single field. Moreover, unlike cereal grain crops, grass seed crops have a high level of natural genetic variability. This variability contributes to the large differences in crop maturity and seed moisture content found in grass seed fields.

Unfortunately, the most widely adopted seed moisture testing methodologies are slow (Silberstein and Anderson, 2011). Thus, it is difficult to make timely management decisions. Harvest is a busy time, and often several crops are reaching maturity at or near the same time in fields spread across the farming operation. A rapid and reliable method to test seed moisture content could increase seed yield and profitability of Oregon's grass seed production enterprises.

Rapid seed moisture testers currently available for use in grass seed crops utilize electrical properties of seeds and are accurate only at seed moisture contents that are too low for determining timing for seed harvest. As a consequence, grass seed growers mostly use air-oven or microwave oven methods that are time consuming and cannot be used in the field.

Near-infrared reflectance spectroscopy (NIR) has been widely used for determining moisture content in agricultural products, including grains and oilseeds. Grain elevators and warehouses sometimes use NIR to test moisture content of cereal grain. Seed moisture determination by NIR in cereal grains and oilseed crops has proven to be rapid and reliable, but no information is available on the testing of grass seed for moisture content under field conditions. Since seed moisture testing by NIR is a secondary method, calibration against a primary seed moisture testing method such as the laboratory air-oven is needed before this technology can be used as a harvest timing tool in grass seed crops. Technological advancements have made it possible to use a portable field-based NIR device for forage and silage analysis at the farm level. Our objective was to determine the feasibility of using portable NIR spectroscopy as a rapid alternative to air drying for determining seed moisture content in grass seed crops.

Materials and Methods

Four grass seed crops were tested in trials conducted at OSU's Hyslop Research Farm near Corvallis in three harvest seasons: 2016, 2017, and 2018. These seed crops were perennial ryegrass, turf-type tall fescue, forage-type tall fescue, and orchardgrass. Together, these four grass seed crops represent more than 60% of the total seed crop acreage in Oregon. The influence of common agronomic practices on seed moisture content and harvest maturity in the grass seed crops was also assessed. These practices included plant growth regulators (PGRs), nitrogen (urea) application rate, and fungicides for stem rust control.

Seed moisture content was determined frequently on each seed crop by use of a Digi-Star Moisture Tracker NIR and by air-oven methods. Operation of the NIR was done per the manufacturer's recommendations, with modifications as needed to accommodate grass seed moisture content determination. Seed sampling for moisture testing by the NIR is the same as for the oven: seeds are stripped from the inflorescences and collected in a container with a tightly fitting lid. Testing began a couple of days past peak flowering of the crops and continued until swathing. Additional seed moisture content measurements were made on seed taken from the swath before combining and on seed that was past harvest maturity in unharvested plots.

Results and Discussion

The seed moisture content of perennial ryegrass as measured by NIR was highly related to the oven test results (Figure 1). Although agronomic treatments such as foliar fungicide products (Quilt and Trivapro) delayed crop maturity for a short time in perennial ryegrass, they had no effect on the ability of the NIR device to measure seed moisture content as compared to the untreated control in all 3 years of testing.

Seed moisture content values measured by the NIR device also showed a very good relationship to the oven test in orchardgrass and tall fescue. Timely, accurate readings of seed moisture content are especially important in orchardgrass, which is very susceptible to seed shattering losses prior to and during harvest.

Trinexapac-ethyl PGR and nitrogen (N) are two of the important agronomic practices in grass seed production. These results show that the use of PGRs and rate of N application had no effect on the ability of the NIR device to measure seed moisture content.

Individual seed moisture tests showed some variability, but less than that observed for other electric moisture meters tested in grass seed crops. Some of this variation in seed moisture content likely resulted from the high degree of natural variability typical of grass seed crops.

Moisture content readings on the NIR device did not correspond directly to oven test results. For example, a harvest recommendation of 35% seed moisture content for perennial ryegrass would correspond to an NIR reading of 24.9%. Measurement of seed moisture content with the NIR was closest to the oven results at low seed moisture content; deviations of the NIR from the oven test ranged from 0 to 5.3% in the seed moisture content increment from 10 to 20% (Figure 2). At high seed moisture content, the values diverged more, with the divergence ranging from 13.2 to 25.3% in the 50–60% seed moisture content increment (Figure 2). In both tall fescue seed crops, seed moisture content measured by the NIR diverged quickly with increased seed moisture content. For perennial ryegrass and orchardgrass, this deviation in NIR seed moisture content from the oven test results was less marked.

Conclusion

The portable Digi-Star NIR device is a promising tool for rapidly measuring seed moisture content for determination of harvest timing in grass seed crops. Spring agronomic practices including PGRs, foliar fungicides, and N application had no influence on NIR determination of seed moisture content.

Deviations of NIR seed moisture content from oven test results are systematic in nature and can be easily corrected with a software update and calibration for these grass seed crops. Specific calibration of the device and measurement protocols are needed before commercial application of this device in grass seed moisture testing.

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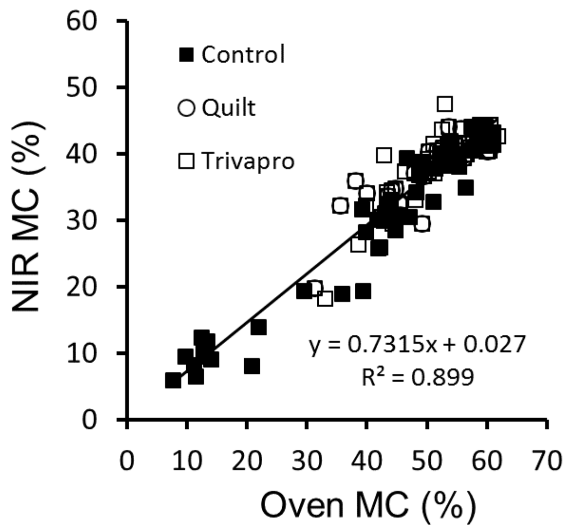

Figure 1. Relationship of seed moisture content from NIR and air-oven methods in perennial ryegrass. Quilt and Trivapro are fungicides applied for rust control. Control was not treated with a fungicide.

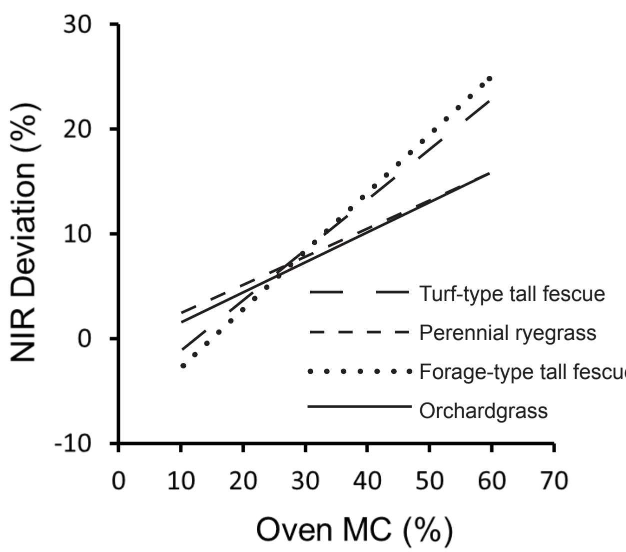

Figure 2. Deviation of NIR reading (seed moisture content) from air-oven seed moisture content in four grass seed crops.

CAN ESSENTIAL OILS BE USED TO CONTROL THE GRAY FIELD SLUG?

M.L. Klein, T.G. Chastain, C.J Garbacik, and R.J. McDonnell

Introduction

To date, minimal effort has been made to develop novel molluscicides for use in seed and forage crops. Recently, however, a diverse group of plant distillates, known as essential oils, have been identified as potential candidates. The increased interest in essential oils has been driven by their classification as "generally regarded as safe" by the Food and Drug Administration and by their exemption from pesticide registration and residue tolerance requirements under Sect. 25(b) of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) (Isman, 2000). The interest in essential oils is widespread, and they have been proven effective against various pests, including insects, mites, fungi, and nematodes (Isman, 2000).

Although assessments have been made on several species of marine and aquatic mollusks (Lahlou and Berrada, 2001; EL-Kamali et al., 2010), to our knowledge there are no published studies of essential oil toxicity on terrestrial slugs and only one published study on their toxicity on terrestrial snails (McDonnell et al., 2016).

The present study was undertaken because essential oils were deemed likely to be lethal to the pest slug *Deroceras reticulatum* (gray field slug) at concentrations unlikely to be phytotoxic to commercial crops. Here we present data on the toxicity of 13 essential oils and one other plant-derived toxin (caffeine) on adults of *D. reticulatum* (Table 1).

Materials and Methods

Determination of LC50 and LC99 values

In this experiment, slugs were exposed to essential oil treatments for 24 hours in ventilated petri dishes. Each petri dish contained a single 9-cm filter paper wetted with 1 ml of either an essential oil solution (essential oil, water, and Tween 80 surfactant), Slug-Fest All Weather Formula (industry standard), water (control), or Tween 80 solution (water and surfactant).

Table 1. Source and cost of essential oils and caffeine used in bioassays.

Essential oil	Cost[1]	Source
	($/liter)	
Birch tar	287.21	*Betula alba*, unspecified location
Bitter orange	41.45	*Citrus bigaradia*, *C. amara* from Brazil, Paraguay (cultivated)
Caffeine	381.59[2]	Thermo Fisher Scientific, Waltham, Massachusetts, USA
Cedarwood	17.89	*Juniperus virginiana* from USA (wildcrafted)
Cinnamon	36.42	*Cinnamomum cassia* from China (wildcrafted)
Clove bud	55.47	*Eugenia caryophylatta* from Madagascar (cultivated)
Eucalyptus	11.93	*Eucalyptus globulous* from China (wildcrafted)
Garlic	42.56	*Allium sativum* from USA, Mexico, Egypt (cultivated)
Lemongrass	16.31	*Cymbopogon citratus* from Guatemala, India (wildcrafted)
Peppermint	44.62	*Mentha piperita* from USA (cultivated)
Pine	20.08	*Pinus strobus* from USA (wildcrafted)
Rosemary	44.09	*Rosmarinus officinalis* from Tunisia, Morocco (wildcrafted)
Spearmint	33.91	*Mentha spicata* from USA (cultivated)
Thyme	82.93	*Thymus vulgaris* from Spain (wildcrafted)

[1]Per-liter cost was calculated based on the maximum volume available (2 oz birch tar, 400 oz all other oils) and dry mass (2.5 kg) for caffeine.
[2]$/kg

Slugs were placed on the filter papers in these petri dishes, exposing them to the essential oil solution. After 24 hours, petri dishes were opened, and slug mortality was assessed. Tests were conducted at several concentrations (0.1, 0.2, 0.25, 0.5, and 1%) to calculate the Lethal Concentration 50 (LC50) and Lethal Concentration 99 (LC99) of each oil. These values denote the concentrations at which 50 and 99% of slugs died, respectively. Thirty slugs were tested at each concentration for each oil, allowing for adequate statistical power.

Efficacy of thyme and spearmint oil foliar sprays in greenhouse microcosms

The two most toxic essential oil treatments from the petri dish bioassay (thyme and spearmint oil) were tested in a greenhouse setting on slugs added to plastic containers (47 cm x 37.8 cm x 28.3 cm) planted with annual ryegrass (variety 'Bounty'). Slugs were added to microcosms when seedlings were in the second-leaf stage, which occurred after approximately 1 month of growth in the greenhouse (October 29 to November 28, 2018). Ten adults were placed in each container, and 60 ml of either thyme, spearmint, Slug-Fest, water, or Tween 80 was applied by handheld spray bottle to the potting media and plant surfaces. This volume is equivalent to the field rate for Slug-Fest (1 oz/gal/100 ft^2) and was chosen to standardize volumes across treatments. Thyme and spearmint oil were applied at 0.5% (approximately double the LC99), and Tween 80 was applied at 1%. Eight randomized blocks were used, resulting in 80 slugs per treatment.

Phytotoxicity assessment of essential oils in perennial ryegrass and tall fescue

The phytotoxic effects of thyme and spearmint oil at 0.25% and 0.5% were determined on two cultivars of perennial ryegrass ('Banfield' and 'APR2190') and two cultivars of tall fescue ('Spyder' and 'Dynamite') grown in the greenhouse. In this trial, seedlings were sprayed with 5 ml, and adult plants with 25 ml, of either thyme, spearmint, Tween 80, or water and were assessed for phytotoxicity symptoms at 3 and 17 days after treatment (DAT). Visual indications of phytotoxicity included necrotic spots, lesions, wilting, and other visible changes in plant morphology. A Minolta chlorophyll meter was used to quantify chlorophyll content, and shoot biomass was also measured by harvesting plants at soil level, drying for 24 hours at 60°C, and then weighing to determine biomass. Growth rate of seedlings was calculated based on the change in shoot biomass during each time interval.

Results and Discussion

Determination of LC50 and LC99 values

After *D. reticulatum* adults were exposed to oils at 1% concentration, birch tar, bitter orange, cedarwood, clove bud, and eucalyptus were all found to be less than 100% lethal and were therefore not subjected to further analysis. Thyme, spearmint, pine, peppermint, garlic, caffeine, rosemary, lemongrass, and cinnamon were all 100% lethal at 1%; therefore, their toxicities were determined using logit analysis. Thyme oil (LC50: 0.148%) was most toxic, followed by spearmint (LC50: 0.153%) and pine (LC50: 0.176%). Thyme, spearmint, and pine oil caused 99% mortality at 0.26, 0.302, and 0.253% respectively. While not statistically more lethal than peppermint or garlic, they were more lethal than all other treatments (Table 2).

Efficacy of thyme and spearmint oil foliar sprays in greenhouse microcosms

Eighty *D. reticulatum* adults were exposed to each treatment with thyme and spearmint (the two most toxic essential oils), Slug-Fest, water, and Tween 80. Slug-Fest was found to be 100% lethal, while spearmint and thyme were both found to be 97.5 % lethal, with only two slugs out of 80 surviving in each treatment. A single slug was missing from the Tween 80 treatment, while all other slugs in Tween 80 and all slugs in water controls were alive, indicating that any dead slugs were almost certainly dying due to the treatments, not other environmental conditions.

Phytotoxicity assessment of essential oils in perennial ryegrass and tall fescue

There were no significant differences among seedlings or adult plants for visual signs of phytotoxicity at both 3 and 17 DAT. However, at 17 DAT, spearmint oil at 0.5% showed a low incidence of visual symptoms in several cultivars. Two 'Spyder' seedlings appeared to have yellow spotted leaves, as well as one 'Banfield' and one 'APR2190'. A 'Spyder' seedling treated with Tween 80 control solution was also found to have yellow spots, indicating that the symptoms may not have been due to the essential oil treatment. These plants recovered, and there was no noticeable effect on overall growth or biomass. Variance among cultivars was observed, but the essential oils produced no quantifiable effect on biomass, growth rate, or chlorophyll content, and the observed degree of variation appeared normal.

Table 2. LC50, LC99, and corresponding 95% confidence intervals for thyme, spearmint, pine, peppermint, garlic, caffeine, rosemary, lemongrass, and cinnamon oils tested on *D. reticulatum* adults.[1]

Oil	N	LC50	95% CI[2]	LC99	95% CI[2]
		(%)		(%)	
Thyme[3]	150	0.148 a	0.111–0.185	0.260 a	0.160–0.360
Spearmint[3]	150	0.153 a	0.113–0.193	0.302 a,b	0.191–0.413
Pine	150	0.176 a	0.147–0.205	0.253 a	0.186–0.320
Peppermint	120	0.199 a,b	0.167–0.231	0.344 a,b	0.241–0.447
Garlic	150	0.204 a,b	0.175–0.233	0.329 a,b	0.237–0.421
Caffeine	144	0.264 b	0.223–0.305	0.535 b,c	0.410–0.660
Rosemary	120	0.307 b	0.244–0.370	0.554 b,c,d	0.384–0.724
Lemongrass	150	0.320 b	0.261–0.379	0.720 d,e	0.561–0.879
Cinnamon	150	0.420 c	0.396–0.444	0.799 e	0.728–0.870

[1]Values with the same letters indicate no statistically significant differences, as determined by comparing the confidence intervals of each oil. Significant differences exist when there is no overlap between confidence intervals.
[2]CI = confidence interval
[3]LC99 values for thyme and spearmint were used in the greenhouse microcosm and phytotoxicity bioassays.

Conclusion
With limited options for controlling slugs in the Willamette Valley, the development of a new molluscicide would represent a significant achievement. Thyme and spearmint solutions appear highly lethal under lab and greenhouse conditions and may prove effective under field conditions. However, these potential new molluscicides must also be cost-effective if they are to be adopted on a wide scale.

The thyme oil used in our bioassays costs $82.93 per liter (based on the maximum bulk volume available for purchase at The Essential Oil Company, http://www.essentialoil.com/), whereas the industry standard liquid metaldehyde (Slug-Fest All Weather Formula) costs $15.26 per liter (Nutrien Ag Solutions, https://www.nutrienagsolutions.com/). Based on recommended application rates for grass seed production (10 oz metaldehyde in 10 gal water/1,000 ft^2), treating an acre with Slug-Fest would cost approximately $196, while treating an acre with 0.5% thyme solution would cost approximately $682. However, spearmint oil, comparably toxic to thyme, costs only $33.91 per liter, which at 0.5% equates to $279 per acre, a more competitive price.

Although more expensive, thyme and spearmint oil have a number of advantages over metaldehyde. For example, metaldehyde has often been shown to only inhibit feeding (Glen and Orsman, 1986), whereas thyme and spearmint oil applications caused rapid mortality (in less than 24 hours). Additionally, *D. reticulatum* are known to exhibit modified behavior in the presence of metaldehyde baits, with overexposure causing slugs to avoid contact with bait pellets. It remains unclear whether a similar behavior would emerge in response to an essential oil, but as evidenced by our greenhouse microcosm study, under relatively low concentrations, these oils can be highly lethal to slugs.

The U.S. Environmental Protection Agency has listed thyme and spearmint oil as exempt from pesticide registration and residue tolerance requirements under Sect. 25(b) of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). This exemption greatly reduces the potential costs and testing requirements of bringing an essential oil product to market. Also, since thyme oil is derived from a botanical source, it should be possible to use this product on certified organic operations, although care should be taken when applying to forage or other feed crops to minimize any unknown effects on livestock.

The results described here suggest that thyme and spearmint oils could be effective botanical pesticides for controlling *D. reticulatum* in ryegrass and tall fescue. Our investigation of these oils will continue with field trials in spring 2019, with the goal of confirming effectiveness and essential oils' utility in actual cropping systems.

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Acknowledgments

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TIMING OF SLUG EMERGENCE IN NEW PERENNIAL RYEGRASS PLANTINGS

G.W. Mueller-Warrant, K.M. Trippe, and R.J. McDonnell

Introduction

Studies conducted from 2014 to 2017 detected moderately stable spatial patterns in emergence of gray field slugs (*Deroceras reticulatum*) over a total of 15 sites newly planted to perennial ryegrass, along with some damage to crop stands. Grower-applied slug baits (metaldehyde or iron-based products) provided sufficient control for all stands to be rated as being successfully established, although multiple applications of bait were needed in some cases and variation in stand uniformity was linked to slug numbers. This was especially so in cases where moderately high numbers (10 or more slugs per blanket) were present within the first 3 weeks after perennial ryegrass germination. The series of single-year analyses (Mueller-Warrant et al., 2015, 2016, 2017) left unresolved several important questions regarding the impact of weather on slug emergence patterns and the possibility of reliably predicting slug emergence in future years.

Materials and Methods

Raw data from tests conducted in the autumns of 2014, 2015, 2016, and 2017 were reanalyzed to quantify relationships between weather patterns and timing of slug emergence. Variables included in regression models included gravimetric moisture of (surface) 2-inch-deep soil samples taken at each individual sampling site on each date, corresponding counts of slugs found underneath "slug blankets" the following mornings, and various data from OSU's Hyslop Research Farm weather station, including daily precipitation, temperature, and evaporation over the summer.

Because slug counts late in the fall might be influenced by cumulative effectiveness of the slug bait applications made by growers and the naturally reduced activity of slugs in colder weather, regression analyses were restricted to the period from planting of perennial ryegrass through peak emergence of slugs. Regressions were conducted across various combinations of sites and years to identify those cases that could be safely grouped together, with the major reason for exclusion of two sites being their status as no-till plantings into old stands of white clover rather than conventional-till plantings following other crops. Because of wide variation in slug density between tests, slug counts at individual sites were expressed as a percentage of the maximum number found in any plot on any date over the whole season at a given site.

Results and Discussion

Our first question was, "What type of relationship existed between soil moisture and slug emergence?" Wetter falls saw slugs emerge over longer periods of time and at broader ranges in surface soil moisture content. Drier falls saw slugs emerge in narrower windows of time and more restricted ranges in surface soil moisture content. In order to accurately quantify this relationship, both the surface and subsurface environments had to be considered. After prolonged dry spells in late summer through early fall, both the deeper soil (depth of 1 foot or more) and the surface soil had to be moist if slugs that had survived the summer as eggs or juveniles were to appear on the surface and damage seedling crops. Our initial examination of the data suggested that thresholds existed somewhere around 30% surface soil moisture before slugs appeared in damaging numbers, but the critical level varied among sites and years, sometimes being as low as 24% or as high as 36%. It was also quite common for an individual slug blanket to have zero slugs even at calendar dates and soil moisture levels with damaging numbers of slugs (about 10) in other plots.

A multisite/multiyear composite model describing slug counts in terms of surface soil moisture and total August–September precipitation was developed that matched the data as well as separate regressions for each individual site-year once the two no-till-into-clover fields were excluded, along with one site in 2017 with almost no slugs (Figure 1). The fields with no-till plantings into clover had high numbers of slugs even at relatively low surface soil moistures early in the fall, unlike all other sites.

Nearly identical patterns were present for 2015 and 2017, the 2 years with the highest amounts of August–September rainfall (2.34 and 2.11 inches). In contrast, there was only 0.82 inch of August–September rainfall in 2016, producing a slug emergence curve that didn't start until soil moisture reached 23% but was higher than the other 3 years, the result of a shorter window in time over which the slugs were present (or equivalently, a later start to their appearance on the soil surface).

Coefficients for this regression were 20.083 for the intercept, -13.981 and 3.254 for linear and quadratic August–September rainfall, and -0.9902, 0.05637, and -0.00065 for linear, quadratic, and cubic surface soil moisture content. The curve for 2014 (August–September rainfall totaled 1.56 inches) spanned the entire range of soil moisture content displayed in the graph, with only slightly higher predicted slug counts for a given soil moisture than in 2015 and 2017.

Given the nuisance involved in measuring surface soil moisture content, the possibility of using weather data to predict soil moisture content was explored. The best model used rainfall in the 10 days prior to sampling and potential evaporation for the preceding 120 days (Figure 2). Predicted soil moisture more closely matched observed soil moisture when separate regressions were run for each year than when using a single model over all 4 years (*R*-square values of 0.797 versus 0.512). More elaborate methods for converting rainfall, temperature, and type of vegetation/ground cover into estimates for soil moisture exist in programs such as the Soil and Water Assessment Tool (SWAT). The coefficients from the 4-year model (41.535 for the intercept, 2.3961 for prior 10-day rainfall, and -0.7054 for 120-day evaporation) could be alternatives to directly measuring surface soil moisture, with the caveat that moisture is likely to be overestimated in the driest soils. Fortunately, slugs are unwilling to emerge to damaging numbers in relatively dry soils, and the model should satisfactorily predict soil moisture from 25% upwards, the range at which slugs become a concern in Figure 1.

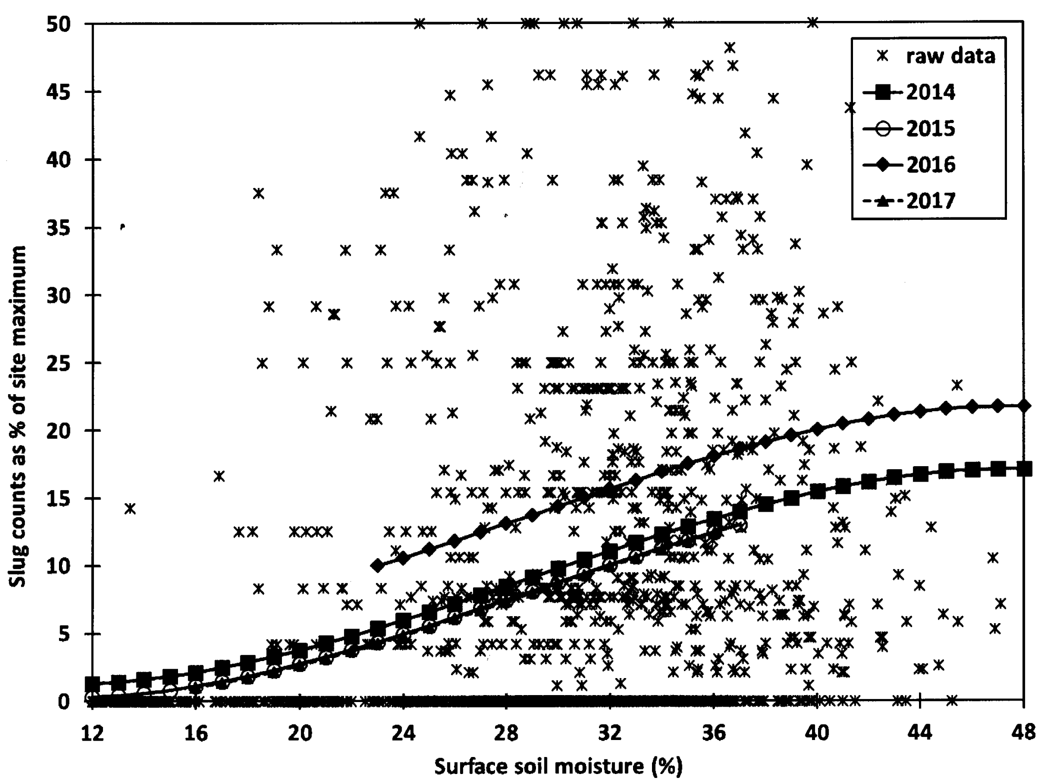

Figure 1. Slug counts over 12 site-years as a function of surface soil moisture content and August–September rainfall totals (1.56, 2.34, 0.82, and 2.11 inches in 2014, 2015, 2016, and 2017, respectively).

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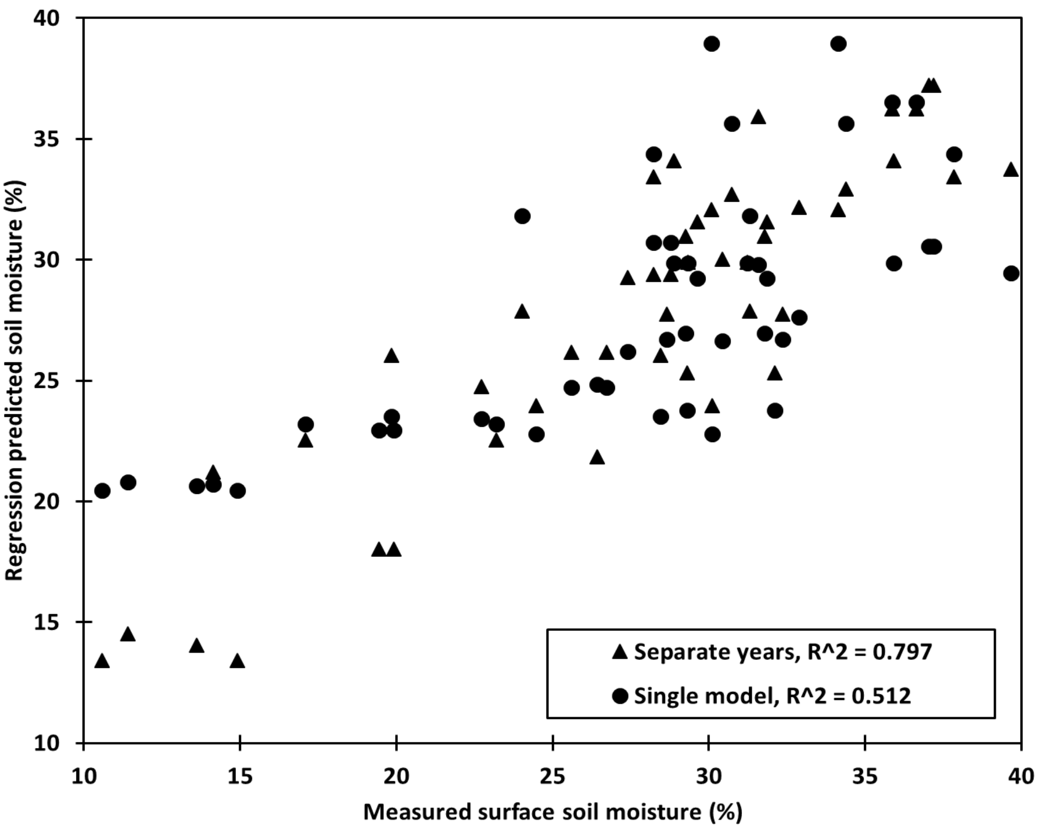

Figure 2. Predicted versus measured surface soil moisture using 10-day prior rainfall and 120-day prior evaporation.

TINY VETCH CONTROL IN CRIMSON CLOVER GROWN FOR SEED

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

Introduction

Crimson clover (*Trifolium incarnatum* L.) grown for seed is an important crop in some areas of western Oregon. For grass seed and wheat growers, it is a dicot rotational crop that provides good economic returns in a system dominated by monocots. To sustain these good economic returns, seed quality and purity are important. Tiny vetch species, *Vicia* spp., are a weed management problem in crimson clover grown for seed because they compete for resources, reducing crimson clover yield, and contaminate clover seed, decreasing its value and increasing losses at the seed conditioner. Controlling tiny vetch in crimson clover grown for seed is especially difficult because both are annual legumes with similar growth habits.

Flumetsulam and 2,4-DB have demonstrated crop safety in red clover (Roerig et al., 2018). 2,4-DB is a Group 4 (synthetic auxin) herbicide that controls many annual and perennial broadleaf weeds. 2,4-DB does not perform as an herbicide until susceptible plants convert 2,4-DB into 2,4-D via enzymes within the plant. Legume crop safety with 2,4-DB is possible due to the low quantity of these enzymes, slow rate of penetration into the foliage, and slow rate of translocation within legume plants. There are no known cases of resistance to 2,4-DB (Shaner, 2014). Flumetsulam is a Group 2 (ALS inhibitor) herbicide with pre- and postemergent activity on broadleaf weeds. ALS-resistant grass and broadleaf weeds are common throughout the United States; however, ALS-resistant broadleaf weeds are rare in the Willamette Valley. The objective of this study was to evaluate herbicides for crop safety in crimson clover and for efficacy in controlling tiny vetch.

Materials and Methods

The trial was conducted in a commercially grown field of crimson clover with a history of tiny vetch in Washington County, OR. Plots were 8 feet x 25 feet in a randomized complete block design with four replications. The first applications of 2,4-DB and flumetsulam were applied to crimson clover with two or three trifoliates when tiny vetch had grown 1–3 inches on November 1, 2017. Additional flumetsulam applications were made to crimson clover with 3–6 inches of growth on March 20, 2018. An untreated check and a grower standard, imazamox + bentazon, were also included. Treatments were delivered in 20 gallons of water/acre and included a nonionic surfactant using a plot sprayer with a 7.5-foot boom.

Visual evaluations of crop injury and weed control were conducted throughout the growing season, and evaluations from May 15, 2018 are reported. The plots were swathed on June 18, 2018 and combined on June 26, 2018, using a Wintersteiger plot combine.

Results and Discussion

Eleven weeks following application, crimson clover injury was 20–23% (data not shown) when 2,4-DB was applied on November 1 at the two higher rates. By May 15, injury was no longer visible, and the plots yielded equivalent to the untreated and grower standard (Table 1). Tiny vetch was not controlled; however, 2,4-DB could be a useful tool for controlling other important weeds in crimson clover due to its crop safety.

Flumetsulam did not injure the crimson clover, and yield was equal to or greater than the untreated check and the grower standard when applied at either timing or rate (Table 1). Control of tiny vetch was 70–83% and was not significantly different between application rates or timing (fall or spring). The control observed was primarily stunting of the tiny vetch plants and suppression of flowering. Since one of the primary objectives is seed purity, and currently registered herbicides provide inadequate control of tiny vetch, flumetsulam would be a valuable tool if it were registered for use in crimson clover.

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Table 1. Tiny vetch control and crimson clover injury and seed yield, 2018.

			Tiny vetch	------------ Crimson clover ------------	
	Rate	Date applied	Control (May 15, 2018)	Injury (May 15, 2018)	Seed yield (June 26, 2018)
			(%)	(%)	(lb/a)
Untreated	—	—	0	0	442
Imazamox	0.039 lb ai/a	Nov. 1, 2017	0	0	447
+ bentazon	0.625 lb ai/a	Nov. 1, 2017			
2,4-DB	0.500 lb ae/a	Nov. 1, 2017	10	0	464
2,4-DB	1.000 lb ae/a	Nov. 1, 2017	0	0	461
2,4-DB	1.500 lb ae/a	Nov. 1, 2017	10	0	419
flumetsulam	0.067 lb ai/a	Nov. 1, 2017	75	0	527
flumetsulam	0.133 lb ai/a	Nov. 1, 2017	83	0	456
flumetsulam	0.067 lb ai/a	Mar. 20, 2018	70	0	503
flumetsulam	0.133 lb ai/a	Mar. 20, 2018	75	0	545
LSD $P = 0.05$			16		73

MONITORING FOR THE RED CLOVER CASEBEARER MOTH (*COLEOPHORA DEAURATELLA*) IN RED CLOVER SEED CROPS OF NORTHEASTERN OREGON

D.L. Walenta, N.P. Anderson, and S.N. Rasmussen

Introduction

The red clover casebearer moth, *Coleophora deauratella* (Lepidoptera: Coleophoridae), is a native European species first reported in 1989 to be a pest in eastern Canada red clover (*Trifolium pretense* L.) seed production (Landry, 1991). *C. deauratella* (CBM) later spread to red clover seed production in the Peace River region of Alberta in western Canada and since 2006 has become a pest of economic concern (Otani, unpublished).

CBM adults lay eggs on newly set red clover heads, and developing larvae feed on developing seed within individual florets. First- to third-instar larvae continue feeding by moving around to other florets until fourth-instar larvae construct a portable case, while continuing to feed on florets, pods, and developing seed. The mature larvae then crawl to the ground during harvest, where they overwinter in sealed cases on the soil surface in crop residue.

A field-based monitoring program was conducted in 2013 and 2014 in Oregon's Willamette Valley, the primary growing region for clover seed in the United States, in response to initial detection of CBM in 2012. As a result, CBM was detected in at least five western Oregon counties (Anderson et al., 2014). Clover seed production in northeastern Oregon occurs on limited acreage, and, due to CBM damage potential, growers indicated a priority need in 2018 to conduct a preliminary pheromone-based monitoring program to determine the presence/absence of CBM east of the Cascade Mountains.

Materials and Methods

On May 25, 2018, sex-pheromone-baited (Evenden et al., 2010) traps were placed in two commercial red clover seed production fields to attract male moths. A 1-year-old stand and a 2-year old stand were selected due to close proximity (< 0.25 mile). One green UniTrap was placed in each field at least 100 feet from the field edge and at crop canopy height. A gray septa baited with the pheromone was placed in each trap and replaced once after 30 days had elapsed. An insecticide vapor strip was placed in the bottom of each trap to euthanize captured moths and was replaced after 30 days. Traps were monitored weekly for 10 weeks, and all monitoring efforts ended on August 3, 2018.

Weekly monitoring activities included: (1) collecting moth specimens from traps for identification and quantification, and (2) evaluating red clover heads for larvae presence and/or damage. Moths were collected from each trap, identified, and counted. Specimens were placed in containers, which were placed in a freezer until identification confirmation could be completed.

Beginning in late June, destructive head samples were collected along a curved arc through the middle section of each field (sixth center pivot tower from the center). The field was split into the north half and south half, and approximately 25 heads were collected from each half. Newly set heads (pink/red) and mature heads (brown) were collected weekly to determine whether larvae and/or damage were present. Two additional red clover seed production fields were also monitored for seed head damage but at limited levels: Site 3 in Union county and Site 4 in Baker County.

Results and Discussion

Moths collected in 2018 have been preliminarily identified as *C. deauratella* due to the pheromone being highly species-specific to *C. deauratella*, as found in studies resulting in a > 99% capture rate in areas where populations of *C. mayrella* and *C. trifolli* also exist (Evenden et al., 2010). Adult moth identification was confirmed by J. Otani, entomologist with Agriculture and Agri-Food Canada, Beaverlodge, Alberta.

Second-year red clover

The pheromone trap collected a total of 1,575 CBM male moths during the 10-week monitoring period. Peak moth capture rates ranged from 114 to 419 moths/week, with peak activity occurring between June 22 and July 20 (Figure 1). Only 3 CBM larvae were collected from destructive sampling of 333 red clover heads from late June through early August. Only 2.7% of the heads (9 heads) exhibited feeding damage, and only 97 florets were damaged out of the total 333 heads evaluated for larvae presence and damage (Table 1). The majority of the damaged heads/florets were identified on the more mature (brown) heads compared to the newly set (red/pink) heads.

First-year red clover

Compared to the second-year red clover stand, CBM adult moths were captured at low numbers (season total = 83 moths) from early June through mid-July. Peak moth capture rates ranged from 4 to 20 moths/week from June 8 through July 13. A total of 154 red clover heads were evaluated for CBM larvae and/or damage, with zero larvae recovery and zero heads/florets exhibiting feeding damage (Table 1).

Site 3, Union County

The grower and his family monitored the Site 3 red clover seed production field for CBM larvae and/or feeding damage on July 13, July 17, and July 20. A total of 72 heads were collected and evaluated (Table 1). No CBM eggs or larvae were found. However, 12 damaged florets were detected during the destructive sampling efforts.

Site 4, Baker County

On August 14, 60 red clover heads were collected and evaluated for CBM larvae and/or feeding damage. No CBM eggs or larvae were found. However, 10 damaged florets were detected during the destructive sampling efforts.

Conclusion

Preliminary monitoring efforts were successful in detecting CBM adult moths at high population levels in well-established red clover seed production fields in the Grande Ronde Valley of northeastern Oregon. Preliminary observations indicate that in 2018 the frequency and severity of seed head damage was very low, at 2% of collected seed heads. CBM is strongly suspected to be present in Baker County, based on characteristic larvae feeding damage to florets, although no larvae were detected in red clover seed head collections. The potential impact of CBM on red clover seed yield and/or quality is not well understood in the Oregon clover seed industry, but recent reports of red clover seed yield loss in the Willamette Valley are causing concern among growers and seed industry representatives.

A priority need to increase pheromone-based monitoring efforts has been identified to further delineate CBM distribution, population dynamics, and potential impact on seed yield in eastern Oregon clover seed production. The greatest challenge is to use monitoring data toward development of an effective CBM management program that protects pollinator populations and mitigates against loss of clover seed yield and quality.

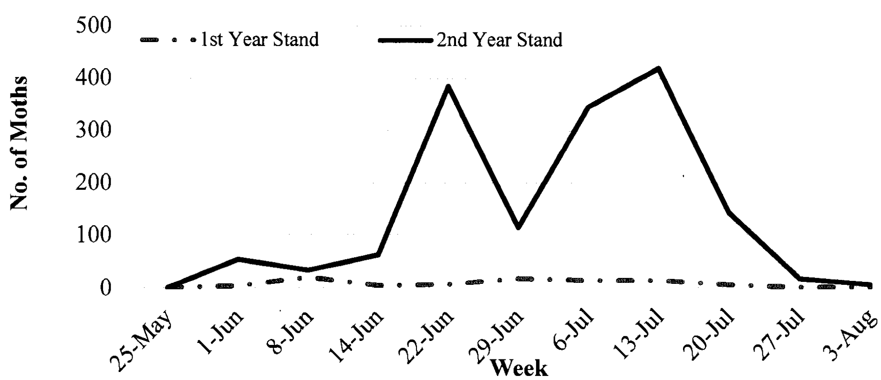

Figure 1. Number of male *C. deauratella* moths collected per week in first-year and second-year red clover seed production fields in the Grande Ronde Valley of northeastern Oregon, 2018.

Table 1. Summary of *C. deauratella* damage level assessments in red clover seed production fields in the Grande Ronde Valley of northeastern Oregon, 2018.

	Heads evaluated	---Red clover heads with---			Damaged florets	Larvae in heads
		Eggs	Damage	Larvae		
	------------	------------	------------	(no.)	------------	------------
2-year stand (N half)	257	0	9	2	97	2
2-year stand (S half)	76	0	0	1	0	1
1-year stand	154	0	0	0	0	0
Site 3, Union County	72	0	3	0	12	0
Site 4, Baker County	60	0	2	0	10	0
Total	623	0	14	3	119	3

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IN-SEASON PLANT NUTRIENT UPTAKE IN ROOTS, SHOOTS, AND FLOWERS OF HYBRID CARROTS GROWN FOR SEED

A.D. Moore, E.A. Jeliazkova, and T.M. Wilson

Introduction

Evaluation of in-season plant nutrient uptake patterns under local field conditions is important for understanding how much of a nutrient is needed by the plant and when the plant has the greatest need for each nutrient. Information on plant nutrient uptake in minor crops, such as carrot seed, is often limited. In-season nutrient uptake was evaluated in Madras, OR, from 2000 to 2002 on hybrid Nantes type 49-1 (Butler et al., 2002; Hart and Butler, 2003). The information generated from these studies established baseline numbers for nutrient uptake that are currently used by carrot seed growers in central Oregon. As these studies were conducted almost 20 years ago, there was interest in better understanding nutrient uptake patterns under current field management practices and for other hybrid Nantes types. There was also interest in understanding how nutrients move through the plant over the course of a growing season, which has not been previously evaluated for all agronomic nutrients in carrot plants produced for seed.

The objective of this study was to evaluate the uptake of nitrogen (N), phosphorus (P), potassium (K), and other nutrients in the roots, shoots, and flowers of hybrid Nantes type 969 carrot plants grown for seed.

Materials and Methods

This study was conducted on two commercial carrot seed production fields near Madras, OR. Both fields were planted to the hybrid carrot variety Nantes 969, with Field #1 planted on August 9, 2017 and Field #2 planted on August 7, 2017. The soil type of both fields was a Madras loam, with similar chemical properties at the 0- to 6-inch soil depth (pH 5.9–6.2; organic matter 1.9–2.0%; NO_3-N 114–187 ppm; Olsen P 30–55 ppm; Olsen K 228–239 ppm). Field #1 was under furrow irrigation following *Poa trivialis* (rough bluegrass). Field #2 was under drip irrigation following summer fallow. Clean seed yield was 154 lb/acre for Field #1 and 177 lb/acre for Field #2.

Sixteen plots were established in a randomized complete block design for each field, with four replicated plots within each field selected randomly for evaluating in-season nutrient uptake patterns. Field #1 had two female sets per plot (one set had four rows with a 30-inch row width), with plot length ranging from 1,157 to 1,248 feet. Field #2 had three female sets per plot, with plot length ranging from 1,290 to 1,595 feet. Plot length differences in Field #2 were caused by the triangular shape of the field.

Plants from female rows were sampled by plot on a monthly basis from October 2017 to August 2018, excluding the months of January and February, when plant growth was minimal. Entire plants (including the roots) were removed from three separate 3-foot-long transects per plot at each sampling event. Soil was removed from roots, and plants were separated into roots, tops, and flowers. Separated samples were weighed, dried at 60°C for 3 days, weighed, and ground to pass a 2 mm sieve. Tissue samples were analyzed for total N, P, and K, plus magnesium (Mg), calcium (Ca), sulfur (S), zinc (Zn), manganese (Mn), iron (Fe), and boron (B). Results from the N, P, and K analyses will be discussed here.

Results and Discussion

Data collected from these two fields have been averaged together for discussion. Mean total biomass over the two fields was 7,645 lb/acre on a dry weight basis (Figure 1a). Approximately 7, 65, and 28% of the biomass accumulated in the roots, tops, and flowers, respectively. Mean total N uptake was 178 lb N/acre on a dry weight basis (Figure 1b). Similar to biomass, approximately 6, 65, and 29% of the N accumulated in the roots, tops, and flowers, respectively. Mean total P uptake was 45 lb P_2O_5/acre on a dry weight basis (Figure 1c). Approximately 6, 54, and 40% of the P accumulated in the roots, tops, and flowers, respectively. Mean total K uptake was 303 lb K_2O/acre on a dry weight basis (Figure 1d). Approximately 5, 76, and 19% of the K accumulated in the roots, tops, and flowers, respectively.

Findings from this research will be compiled with data previously reported by Hart and Butler (2003) and Butler et al. (2002) to inform growers, agronomists, and researchers on the amount of nutrients used by hybrid carrot plants grown for seed production, the time of the season when the plant will use the nutrients, and where in the plant the nutrients are accumulated at various plant growth stages.

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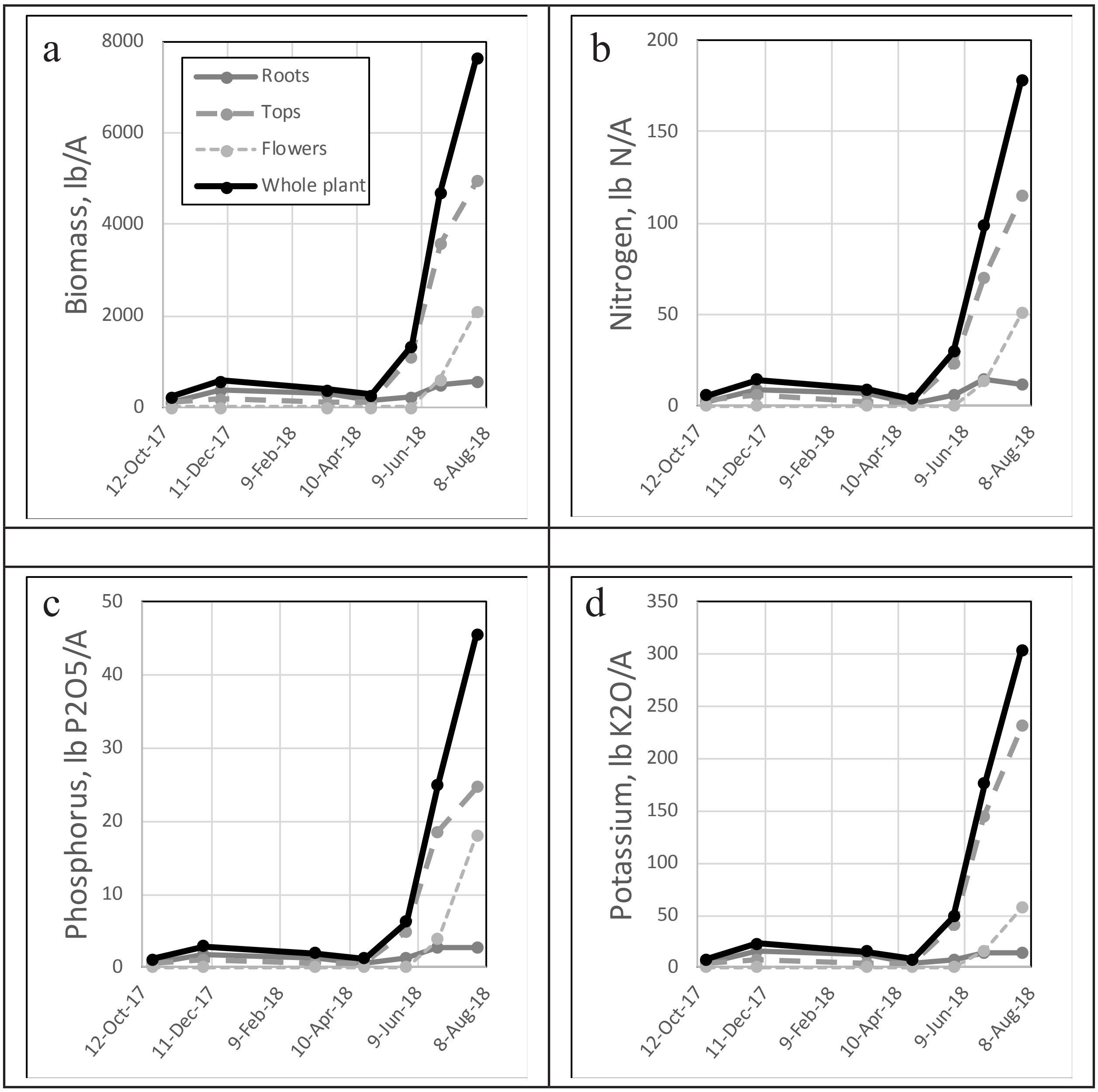

Figure 1. Mean in-season biomass and nutrient accumulations for two hybrid Nantes 969 carrot seed production fields in Madras, OR, from October 2017 to August 2018. Soil type is Madras loam.

ARE CURRENT RECOMMENDATIONS TOO HIGH? EXAMINING THE NITROGEN FERTILIZER NEEDS OF DRY FIELD PEAS IN THE WILLAMETTE VALLEY

C.S Sullivan

Introduction

Field crop producers in the Willamette Valley are always on the lookout for alternative crops to add to their grass seed systems and are particularly interested in broadleaf crops. Dry field peas grown for seed (either for the sprouting or cover crop market) are a rotational crop that has expanded noticeably in Willamette Valley acreage over the past several years. While field peas were grown extensively in the region decades ago, it is a new crop for many growers, and optimal management practices are still emerging. For example, nitrogen (N) fertilizer rate recommendations can vary from 20 to 100 lb N/acre.

The only fertilizer guide (Gardner et al., 2000) for field peas grown in western Oregon, which was revised in 1983, does not recommend any N inputs for a properly inoculated legume crop in western Oregon. Similarly, studies from the Canadian prairies and North Dakota have shown that properly inoculated field peas can meet all of their N requirements through N_2 fixation, and no starter N is needed (Gan et al., 2004). Research from North Dakota has shown that 60–80% of the N found in a field pea is derived from N_2 fixation, with the remainder being derived from soil N sources (Franzen, 1998). Furthermore, it has been shown that high levels of available soil N (more than 50 lb/acre) reduce nodulation because the legume crop preferentially uses soil N, and the grower then misses out on using "free N" from fixation.

Nearly all of the research conducted on dry field peas has been done in climates that are very different from western Oregon, such as semiarid environments where soils carry over N from the previous crop. In western Oregon, it is assumed that most NO_3-N present in the fall is leached and lost over the winter.

Research suggests that in very N-limited fields (less than 20 lb NO_3-N/acre), a small amount of top-dressed N (about 20 lb N/acre) is recommended to initiate root nodulation and symbiotic N_2 fixation (Miller et al., 2005). Fields in western Oregon may fall into this category, in which case a small addition of N would make sense. However, the average N rate used in the southern Willamette Valley is approximately 50 lb N/acre.

It would benefit growers to both observe and measure field pea performance at different N rates to learn whether they could cut down on input costs by maximizing the N_2-fixing abilities of field peas. This research project aimed to measure field pea performance at different N rates to determine whether fertilizer N rates could be reduced. With an average price of $0.30/lb for field peas, any input cost savings would be beneficial to growers.

Objectives:

- To demonstrate the effect of zero N on field pea growth and yield
- To measure the effect of N rate on root nodulation, seed yield, and seed yield components
- To develop recommendations for N use in field pea production based on research results and to disseminate this information to growers.

Materials and Methods

Three trials were established on growers' fields in the spring of 2016: one trial each in Polk, Linn, and Benton counties. Sprouting peas (variety 'W-II') were inoculated and planted with grower equipment on April 6 (Polk), April 7 (Linn), and April 9 (Benton). The Polk field was drilled into perennial ryegrass stubble, the Linn field was drilled into wheat stubble, and the Benton field was planted into worked ground that had previously been in annual ryegrass grown for seed. The experiment was set up as a randomized complete block design with three replicates. The plots measured 25 feet x 300 feet. Preplant soil samples (0–6 inches, 6–12 inches, 12–24 inches) were taken at each study site. See Table 1 for field activity dates.

Table 1. Trial activities and dates completed at three field pea trial sites, 2016.

Activity	Polk	Linn	Benton
Preplant soil sample	Apr. 1	Mar. 30	Apr. 4
Field planting	Apr. 6	Apr. 7	Apr. 9
Plots fertilized	Apr. 29	May 2	Apr. 29
Plots swathed	Aug. 1	Jul. 27	Jul. 26
Plots combined	Aug. 4	Aug. 11	Aug. 13
Postharvest soil sample	Aug. 18	Aug.17	Aug. 18

At the four-leaf stage of the peas, four fertilizer treatments were applied with an Orbit Air Spreader to achieve a comparison of 0, 40, 80, and 120 lb N/acre using urea fertilizer (46-0-0). Roots from each plot were sampled approximately 6 weeks after planting, and root nodulation was assessed visually according to the Nodulation and Nitrogen Fixation Field Assessment Guide published by the Saskatchewan Ministry of Agriculture (Risula, 2016). In this protocol, nodulation and N fixation potential of a legume plant are scored based on: (1) plant growth and vigor, (2) nodule color and abundance, and (3) nodule position. Plants are awarded higher scores for greener and more vigorous plants, greater numbers of nodules having pink pigments, and nodules positioned both near the crown and laterally. Scores from each category were summed to give a total score for each plant, with the total score corresponding to one of three categories: (1) effective nodulation, (2) less effective nodulation, or (3) poor nodulation.

Plant biomass samples (1 ft^2) taken at harvest were separated into stems and pods to be analyzed separately. The stems were analyzed for total biomass, %N and %C. Pods were processed to measure the number of pods/stem, pods/ft^2, peas/pod, and peas/ft^2. A 15-foot swath was taken down the center of each plot with grower equipment, and each plot was combined separately to calculate yields using a weigh wagon. Postharvest soil samples (0–6 inches) were taken from each plot to determine residual soil N.

Results and Discussion

The preplant soil samples revealed sufficient starter N (at the 0- to 12-inch depth) at all sites and high levels at some sites: 79 lb NO_3-N/acre at Polk, 38 lb NO_3-N/acre at Linn, and 65 lb NO_3-N/acre at Benton. All sites had sufficient soil P and K levels and suitable soil pH for field pea production. Averaged across all sites, root nodulation appeared to be more effective at the 0 and 40 lb N/acre rates and less effective at the higher rates (Table 2). None of the assessed plants had "poor nodulation," even though N fixation is generally considered to be depressed when soil N is more than 50 lb N/acre.

There were no significant differences or trends in the plant samples taken at harvest, including N uptake, C:N ratio, biomass, or seed yield components (Table 2). There were no significant differences found in pea seed yield between the fertilizer treatments at any site (Table 2). High yields were maintained with zero fertilizer N applied, and trial yields were comparable to grower field average yields (Table 3). Residual soil N did tend to be higher at the 80 and 120 lb N rates (Table 2).

The first-year results suggest that the fertilizer N rate did not impact yield (Table 3) or seed yield components, but higher N rates resulted in higher soil residual N levels at the end of the growing season (Table 2). It is likely the preplant soil N level was sufficient to supply the pea crop and that fertilizer N was not needed. The 2016 results indicate that a successful pea crop can be grown with zero N fertilizer without impacting overall seed yield or seed yield components.

Table 2. Harvest stem and pod characteristics, nodule ratings, yield, and postharvest soil sample results averaged across three field pea trials in the Willamette Valley grown under different fertilizer N treatments, 2016.

Tmt	Harvest plant sample[1] --------- (stems only) ---------									
N rate	N uptake	C:N ratio	Biomass	Nodule rating	Yield	Pods/ft^2	Pods/stem	Peas/pod	Peas/ft^2	Postharvest soil N[2]
(lb/a)	(lb/a)		(lb/a)		(lb/a)	(no.)	(no.)	(no.)	(no.)	(lb/a)
0	88	37	6,242	Effective	3,439	65	6.4	5.0	313	11 b
40	87	31	5,791	Effective	3,302	53	6.1	5.2	281	16 ab
80	74	34	5,876	Less effective	3,439	59	5.7	5.3	312	25 a
120	70	41	6,172	Less effective	3,492	66	6.3	4.7	311	26 a

[1] Plant samples were collected on July 22, 2016.
[2]Results followed by a different letter are significantly different at LSD (P = 0.05).

The average N application rate of growers in this study was 55 lb N/acre. A zero N application rate would result in $32.50/acre savings (N at $0.65/lb). In additional to saving money, lower fertilizer rates would reduce the environmental risk of residual N in the fall. The trial will be repeated in 2019.

Table 3. Yield results of three field pea trials in Polk, Linn, and Benton counties under different N rates as compared to the grower's field average in 2016. Grower fertilizer rate included.

	------------------ Yield	------------------	
Treatment	Polk	Linn	Benton
(lb N/a)	------------------ (lb/a)	------------------	
0	2,714	3,817	3,787
40	2,613	3,585	3,707
80	2,738	3,704	3,876
120	2,783	3,823	3,869
Trial average	2,712	3,732	3,809
Grower field average	2,800	3,500	3,430
Grower fertilizer rate	60 lb N/a	65 lb N/a	40 lb N/a

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Available online at
https://cropandsoil.oregonstate.edu/seed-crops/seed-production-research-reports

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