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Department of Crop and Soil Science Ext/CrS 150, 4/15

The following authors have contributed to this report.

Central Oregon Agricultural Research Center
- J.K.S. Dung, Assistant Professor, Plant Pathology
- G. Sbatella, Assistant Professor, Weed Scientist
- S. Twelker, Biological Sciences Research Technician

Cooperative Extension Service—OSU
- N.P. Anderson, Regional Field Crops Extension Agent, North Willamette Valley
- M.E. Mellbye, District Extension Agent Emeritus
- D.L. Walenta, Extension Crops Specialist, Union County

Department of Crop and Soil Science—OSU
- D. Angsumalee, Graduate Student
- T.G. Chastain, Associate Professor, Seed Crop Physiology
- D.W. Curtis, Senior Faculty Research Assistant, Weed Science
- A.S. DuVal, Graduate Student
- S.G. Elias, Associate Professor, Senior Research, Seed Science and Technology
- C.J. Garbacik, Senior Faculty Research Assistant, Seed Crop Physiology
- A.G. Hulting, Associate Professor, Extension Weeds Specialist
- C.A. Mallory-Smith, Professor, Weed Science
- K.C. Roerig, Faculty Research Assistant, Weed Science
- W.C. Young III, Professor Emeritus, Extension Seed Production

Hermiston Experiment Station
- P.B. Hamm, Station Director and Professor Emeritus

National Forage Seed Production Research Center—USDA-ARS
- S.C. Alderman, Professor and Research Plant Pathologist
- G.M. Banowetz, Research Plant Physiologist and Research Leader
- S.M. Griffith, Professor and Research Plant Physiologist
- G.W. Mueller-Warrant, Associate Professor and Research Agronomist
- K.M. Trippe, Research Microbiologist
- G.W. Whittaker, Research Hydrologist

IRRIGATION AND TRINEXAPAC-ETHYL EFFECTS ON SEED YIELD IN A SECOND-YEAR RED CLOVER STAND

T.G. Chastain, N.P. Anderson, C.J. Garbacik, D. Angsumalee, and S.G. Elias

Introduction

Red clover is the most widely grown legume seed crop in the Willamette Valley. In previous articles, we've shown that trinexapac-ethyl (Palisade), an acylcyclohexanedione plant growth regulator (PGR), and irrigation can increase seed yield of red clover under Willamette Valley conditions (Anderson et al., 2012; Chastain et al., 2013).

In this article, we will examine the effects of irrigation and trinexapac-ethyl (TE) as well as potential interactions of irrigation and the PGR on seed yield and yield components in a second-year stand of red clover.

Methods

Two plantings (2011 and 2012) of red clover seed crops were established in the fall at Hyslop Crop Science Research Farm near Corvallis, and each has been followed over a two-year period to examine the effects of irrigation and PGRs. PGR treatment subplots (11 feet x 50 feet) were randomly allocated within irrigated and non-irrigated main plots in a split-plot arrangement of treatments in a randomized block experimental design. Trials were replicated in four blocks. The TE PGR treatments were made on the subplots at two application timings and at five rates of TE. Control plots were not treated (Table 1).

Table 1. Trinexapac-ethyl (Palisade EC®) application timings and rates used in a second-year stand of red clover grown for seed production.

Application timing (BBCH scale)	TE application rate
	(pt/acre)
Untreated control	—
BBCH 32 (stem elongation)	1
	2
	3
	4
	5
BBCH 50 (bud emergence)	1
	2
	3
	4
	5

The red clover seed crop was flailed in mid-May (prior to bud emergence), and residue was removed from the field. Once regrowth occurred, approximately four inches of irrigation water was applied to main plots over a two-day period by using a custom-designed Pierce AcreMaster linear system equipped with minimum-drift Nelson sprinklers. This single irrigation was strategically timed to coincide with first flowering (BBCH 60).[1] TE was applied at rates listed in Table 1 to subplots at stem elongation (BBCH 32) and bud emergence (BBCH 50). Seed was harvested with a small-plot swather (modified JD 2280) and threshed with a Hege 180 small-plot combine. Harvested seed was processed through an M2-B Clipper cleaner, and clean seed yield was determined.

Plots were sampled at peak bloom (BBCH 65) to determine the number of heads (inflorescences), florets within the heads, primary stems, and above-ground biomass. Harvest index was determined for each plot based on harvested seed yield and above-ground biomass. Seed weight was measured by counting two 1,000-seed samples from harvested, cleaned seed material and determining the weight. Seed number was calculated based on seed yield and 1,000-seed weight values obtained from each plot.

Results and Discussion

Irrigation increased seed yield of red clover (Tables 2 and 3). Rainfall for July and August was only 37% of the long-term average. These dry conditions were preceded by a normal spring, so the water was clearly needed by the crop during the critical flowering period for best seed yield results. The strategic irrigation increased seed yield by 10% over the non-irrigated crop in the second-year stand (Table 2). Irrigation also increased yield in the first-year stand (results not shown). Above-ground biomass, stem number, harvest index, and inflorescence production were not influenced by irrigation (Table 3). Seed weight was increased by nearly 5% with irrigation (Table 2). Seed yield was likely increased by irrigation because of increases in both seed weight and seed number. Irrigation had no effect on cleanout of the crop. There were no

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[1] BBCH refers to the Biologische Bundesanstalt, Bundessortenamt und CHemische Industrie system of crop development staging.

interactions of irrigation and PGR for any of the seed production characteristics (Table 3).

Seed yield was increased by TE with applications made at stem elongation (Figure 1). The 1 pint/acre rate increased seed yields by 10% over the untreated control, while higher rates (2 to 5 pints/acre) increased seed yield by an average of 18%. Application of TE at bud emergence had no effect on yield at the 1 pint/acre rate. At rates of 2 to 5 pints/acre, TE application decreased yield by 8 to 21%, depending on the rate used. Cleanout was significantly reduced by applications of TE at stem elongation but not at bud emergence (data not shown).

There are several possible explanations for the seed yield trends observed with regards to application timing and rate of TE. The application of TE at stem elongation either had no effect on the number of inflorescences produced or increased production at higher rates (Figure 2). On the other hand, inflorescence production tended to be reduced by applications of TE at bud emergence. With reduced inflorescence production, seed yield potential can also be reduced.

Additional contributing factors to the seed yield trends were seed weight and seed number. Application of TE at both timings reduced seed weight, especially with increasing rates of TE (Figure 3). But seed weight was reduced more by TE applications at bud emergence than by applications at stem elongation. Seed number was greatly increased by TE applications at stem elongation, but applications at bud emergence had little effect on seed number (Figure 4). With applications at stem elongation, seed number was increased in proportion to the rate of TE applied, reaching a maximum at 4 pints/acre.

Since seed yield is the product of seed weight and seed number, small reductions in seed weight resulting from TE application at stem elongation were more than offset by increased seed number, leading to increased seed yields. In bud emergence timings, on the other hand, somewhat greater reductions in seed weight were not compensated for by increases in seed number; as a result, seed yield was reduced.

This is the second in a series of reports on irrigation and PGR effects in red clover seed production. Future updates will continue to follow the results of the two experimental red clover seed fields as they age.

Acknowledgments
The authors wish to thank the Oregon Seed Council and the Oregon Clover Commission for their support of this work.

Table 2. Irrigation effects on a second-year red clover seed crop in 2013.

	Treatment[1]	
Characteristic	Irrigated	None
Seed yield (lb/acre)	746 b	678 a
Seed weight (mg)	1.71 b	1.63 a
Seed number/m^2 (x 10^4)	48.8 b	46.5 a
Heads/ft^2	71 a	75 a
Cleanout (%)	3.7 a	3.3 a

[1] Means in rows followed by the same letter are not significantly different ($P = 0.05$).

Table 3. Analysis of variance for effects of irrigation and PGR in a second-year stand of red clover seed in 2013.[1]

	Source of variation		
Characteristic	Irrigation (I)	PGR (P)	I x P
Above-ground biomass	NS	NS	NS
Stem number	NS	NS	NS
Harvest index	NS	***	NS
Seed yield	**	***	NS
Seed weight	**	***	NS
Inflorescence number/ft^2	NS	*	NS
Cleanout	NS	*	NS

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

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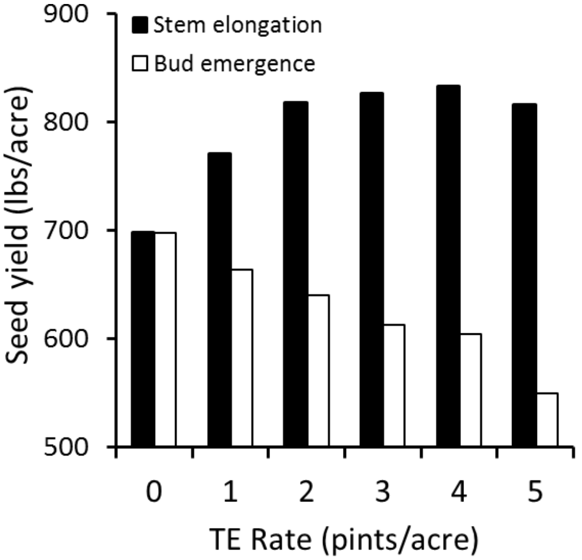

Figure 1. Effect of trinexapac-ethyl applied in two timings on seed yield in a second-year stand of red clover.

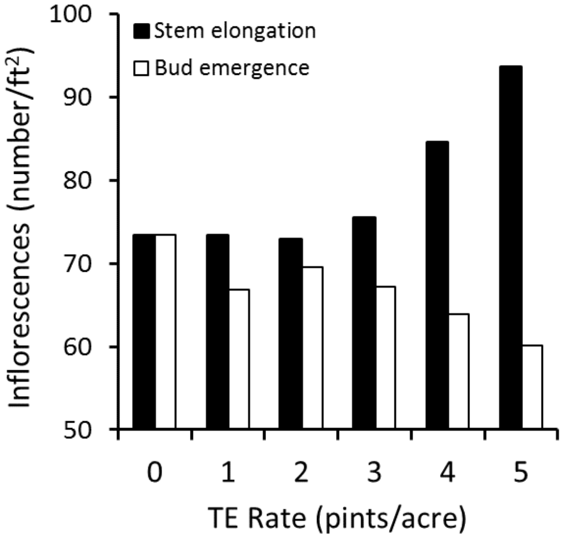

Figure 2. Effect of trinexapac-ethyl applied in two timings on inflorescence production in a second-year stand of red clover.

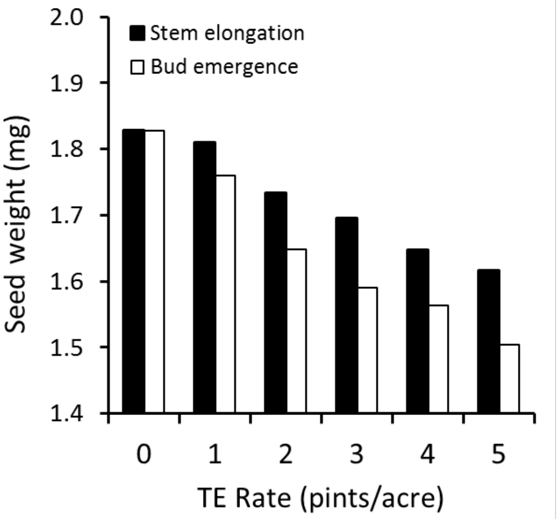

Figure 3. Effect of trinexapac-ethyl applied in two timings on seed weight in a second-year stand of red clover.

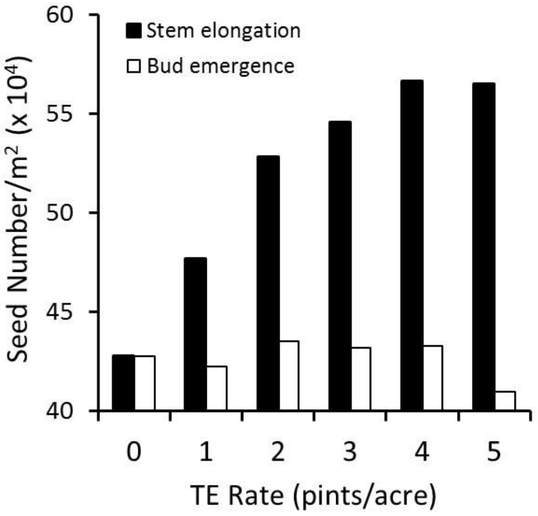

Figure 4. Effect of trinexapac-ethyl applied in two timings on seed number in a second-year stand of red clover.

EFFECT OF PLANT GROWTH REGULATORS AND IRRIGATION ON PHYSIOLOGICAL MATURITY AND SEED QUALITY OF RED CLOVER

D. Angsumalee, S.G. Elias, N.P. Anderson, T.G. Chastain, and C.J. Garbacik

Introduction

Red clover is an important forage legume and is widely grown as a seed crop in western Oregon. Red clover seed crops are grown under both irrigated and non-irrigated regimes. Foliar-applied plant growth regulators (PGRs) have been widely used on temperate grass seed crops in Oregon and other parts of the world for several decades. This practice was adopted due to documented seed yield increases and reduction in lodging (Zapiola et al., 2006). Until recently, little information has been known about the effect of PGRs on crop maturation, seed quality, and yield of red clover. Currently, the acylcyclohexanedione PGRs are most commonly used in Oregon seed production. Two compounds are registered as lodging control agents in grass seed crops in Oregon: trinexapac-ethyl (TE), trade name Palisade EC® (Syngenta), and prohexadione-calcium (PC), trade name Apogee® (BASF).

A study conducted in Norway reported that seed yield was increased by 21% in red clover crops when TE (Palisade) was applied at stem elongation (Øverland and Aamlid, 2007). Anderson et al. (2012) conducted on-farm trials that revealed positive yield results with applications of TE on red clover seed in Oregon. Based on these results, TE was registered for use on red clover seed crops in Oregon in 2013. Field observation over two years of on-farm trials in Oregon indicated that in addition to increasing seed yield, TE treatments also promoted earlier crop maturation that allows more time for harvest operations. However, the effect of early maturation of red clover seed treated with TE on seed quality is unknown.

Using PGRs may alter seed development and maturation time, resulting in difficulty in determining the optimum time for harvest, but without sacrificing the quality of the seed, especially viability and vigor. Although some research looked at yield potential and lodging of red clover seed treated with PGRs, very little work has been done regarding the effects of PGRs on physiological development and maturation in relation to seed quality of red clover. However, one study investigated similar effects in canola (Elias and Copeland, 2001), and the methodology used in that study could be employed to explain the relationship between physiological maturity and seed quality in red clover.

Oliva et al. (1994) showed that a single irrigation strategically timed to coincide with flowering doubled seed yield over the non-irrigated control in red clover. The yield component most associated with the irrigation-induced increase in seed yield was the number of seeds per floret, with additional contribution from the seed weight component. However, there is no published research on the effect that a combination of PGR application and irrigation might have on physiological maturity (PM) and seed quality of red clover. Therefore, the objectives of this research were to determine the effect of irrigation, PGRs (TE and PC), and the interaction between them on (1) PM of red clover seed and (2) seed quality at different stages of maturity.

Materials and Methods

Research was conducted at Hyslop Crop Science Research Farm near Corvallis, OR. Red clover was planted in late September 2011. A randomized complete block design was used. The main plots consisted of irrigated and non-irrigated treatments. Within each main plot, eleven PGR treatments were applied to randomly selected subplots (Table 1). There were four replications of each treatment.

Table 1. Plant growth regulator treatments (trinexapac-ethyl [TE] and prohexadione-calcium [PC]) applied to each main plot (irrigated and non-irrigated) in 2012 study.

Subplot		PGR application timing	
		Stem elongation	Bud formation
1	Control (untreated)	—	—
2	Palisade (TE) 1 pt/acre	✓	—
3	Palisade (TE) 2 pt/acre	✓	—
4	Palisade (TE) 3 pt/acre	✓	—
5	Palisade (TE) 4 pt/acre	✓	—
6	Palisade (TE) 1 pt/acre	—	✓
7	Palisade (TE) 2 pt/acre	—	✓
8	Palisade (TE) 3 pt/acre	—	✓
9	Palisade (TE) 4 pt/acre	—	✓
10	Apogee (PC) 7.4 oz/acre	✓	—
11	Apogee (PC) 14.8 oz/acre	✓	—

The red clover seed crop was flail mowed in mid-May, and the residue was removed from the field. The TE treatments were applied at stem elongation and bud formation stages, while the PC treatment was applied once at stem elongation stage. Irrigation was applied at flower development stage by using a custom-designed Pierce Acre Master Micro Linear system equipped with minimum-drift Nelson sprinklers.

Physiological and visual characteristics of seeds

Inflorescences (heads) were sampled from the field plots following the protocol established by Elias and Copeland (2001). After full flowering (anthesis) and seed formation, seed and head color was recorded. Seed moisture content and dry weight of seeds were determined twice each week, from the initiation of seed development through seed harvest. Seed color, dry matter content, and seed moisture content were measured to determine the time of physiological maturity (PM, maximum seed dry weight) and harvest maturity (HM, when seeds reach proper moisture content for direct combine) of red clover seed.

Seed quality characteristics

Seed viability was determined weekly starting from the time of seed formation by the standard germination test (SGT) and the tetrazolium test (TZ). Seed vigor was ascertained by the cold test (CT) and accelerated aging tests (AAT). Germination percentage and viability by TZ percentage were recorded. All quality tests were conducted using the protocols of the Association of Official Seed Analysts (AOSA, 2009; AOSA, 2012).

Statistical analysis

The study was conducted over a two-year period. The data presented in this report are from Year 1 of the study. Analysis of variance (ANOVA) and mean separation by the Least Significant Difference test (LSD) were used to analyze the data. The MSTAT statistical package (Michigan State University) was used.

Results and Discussions

Effect of PGRs on physiological characteristics of seeds

The TE and PC application rates had no significant effects on seed moisture content (SMC). Seed moisture content of all treatments decreased rapidly after PM and was within 10% after one week. Seed dry weight (SDW) of all treatments increased gradually following seed formation, but did not change significantly after PM (Figure 1). The TE application reduced seed dry weight, while PC did not. Although TE reduced SDW and seed size, the number of seeds per head was increased over the untreated control, compensating for the decrease in SDW (data not shown). The application time of TE had no significant effect on SMC or SDW. Year 1 results did not indicate that TE treatments promoted earlier seed maturation as we expected.

Effect of irrigation on physiological characteristics of seeds

Irrigation had significant effects on SMC and SDW of red clover treated with TE and PC in Year 1. During seed development, the irrigation treatment resulted in higher SMC and SDC compared to non-irrigated seed. Irrigation resulted in a delay in PM and HM (Figure 1). The relative increase of SMC may be attributed to the delay in maturity compared to non-irrigated seeds. Irrigation also resulted in higher SDW compared to non-irrigated treatments. Consequently, seed yield from irrigated treatments was 10% higher than yields from treatments without irrigation (Figure 2). Similar results were reported by Chastain et al. (2013).

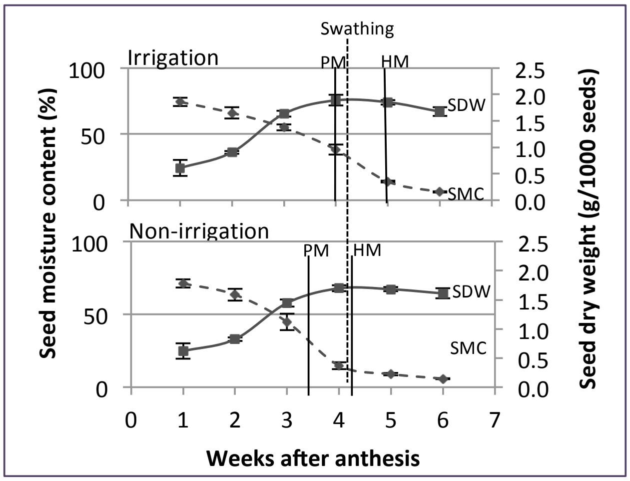

Figure 1. Seed moisture content (SMC) and dry weight (SDW) of red clover during seed development, irrigated and non-irrigated treatments. Where error bars regions do not overlap, treatments are significantly different. Curves represent the average of all PGR treatments. PM = physiological maturity; HM = harvest maturity.

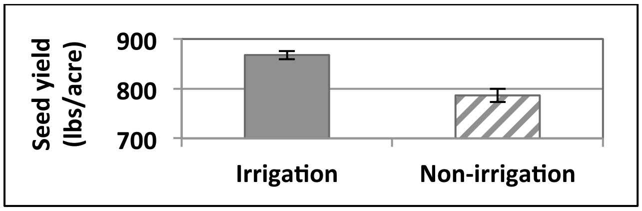

Figure 2. Seed yield of irrigated and non-irrigated red clovers, average of all PGR treatments. Statistical significance is indicated by non-overlapping error bar regions.

Table 2. Change in red clover head and seed color at different stages of seed development averaged over all treatments.

Weeks after anthesis	Seed color	Head color
1	Light green	Pale pink petals with green sepals
2	Light green	Pale to light brown petals with green sepals
3 } (PM)[1]	Light green to pale green	Light brown petals with green sepals
4	Pale green to pale yellow	Light to dark brown petals with pale green sepals
5 } (HM)[2]	Yellow or yellow-purple	Dark brown petals with light brown sepals
6	Yellow or yellow-purple	Dark brown petals with dark brown sepals

[1]PM = Physiological maturity
[2]HM = Harvest maturity

Visual indicators of physiological and harvest maturity

Changes in head and seed color were observed throughout development and maturation (Table 2). At the early stages of seed development, the heads contained pink petals with green sepals, and the seeds were tiny, soft, and translucent to light green. With further development, the heads contained pale pink petals with green sepals, and the seeds were pale green to yellow. At PM, the heads contained light brown petals with green sepals, and seeds ranged from pale green to pale yellow. The seeds were firm but not hard and could be smashed by a fingernail, mostly likely because the SMC was high, approximately 35–40%.

As head and seed color changed throughout the period of seed development and maturation, the SDW also changed (Figure 1). Therefore, the change in head and seed appearance can be indicators of PM in red clover. Visual indicators of PM have also been suggested for soybean (Gibkpi and Crookston, 1981), canola (Elias and Copeland, 2001), and cuphea (Berti et al., 2007).

Seeds reached HM about one week after PM. At HM, both petals and sepals were dark brown, and seeds were yellow or various shades of yellow-purple. The seeds were hard and could not be smashed by a fingernail or a needle because the moisture content was less than 10%. These hard seeds with low moisture content were suitable for direct combine.

Our results indicated that optimum swathing time occurs about four weeks after flowering (anthesis) for non-irrigated red clover and slightly earlier for irrigated red clover. Optimum threshing time or direct combine is one to two weeks following swathing, depending on weather conditions.

Seed quality characteristics

Seed quality from all treatments improved after PM (Table 3). Similar results were reported by Elias and Copeland (2001) in canola. In other crops, such as soybean, seeds reached maximum quality at PM (Miles et al., 1983). This difference may be the result of a different physiological change, such as the seed hormone ratio.

Irrigation, PGR application rate, seed maturity stage, and the interactions among them had no significant effects on seed quality. Seed quality at HM was not significantly different among irrigation and PGR treatments (Table 3). Seed viability as measured by the TZ test ranged from 93 to100%. Germination percentage from SGT and CT was also high and ranged from 88 to 100%. This indicates that the cold temperature stress in the CT did not affect seed vigor at HM, suggesting that maximum viability and vigor are reached at HM. However, the germination percentage from the AAT fluctuated, and results were not as consistent as those from other tests. Therefore, the AAT was not a reliable method to measure seed vigor of red clover in this study.

Seed yield

The effects of irrigation and PGR on red clover seed yield and yield component have been earlier reported by Chastain et al. (2013). Results from Year 1 of this work indicated that seed yield was increased by irrigation but was not significantly affected by PGR treatments.

This work is being carried out for a second year, and results from the two-year study period will be reported in a future article.

Table 3. Seed viability and vigor of irrigated and non-irrigated red clover at different stages of seed development and maturation and with different TE rates (pt/acre) as measured by TZ, SGT, CT, and AAT.[1]

Weeks after anthesis	Irrigated[2]					Non-irrigated[3]				
	Untreated	TE1	TE2	TE3	TE4	Untreated	TE1	TE2	TE3	TE4
Viability										
Tetrazolium test (TZ)										
	Viability (%)									
3	50	58	58	83	74	93	98	99	99	94
4	66	86	76	80	60	98	99	98	93	96
5	100	100	100	100	98	100	100	100	100	100
6	96	100	99	96	100	100	99	96	99	98
LSD (*P* = 0.05) = 7.9										
Standard germination test (SGT)										
	Germination (%)									
1	13	5	9	10	9	13	25	24	26	33
2	20	33	13	32	19	90	90	61	70	63
3	62	56	33	28	26	100	74	98	95	83
4	68	81	80	98	90	93	91	88	88	100
5	100	99	99	95	99	100	98	94	98	99
6	95	98	95	93	98	91	98	99	94	95
LSD (*P* = 0.05) = 10.3										
Vigor test										
Cold test (CT)										
	Germination (%)									
3	18	16	34	36	28	93	95	55	65	66
4	30	55	34	46	29	95	94	95	84	98
5	100	99	98	99	99	100	98	99	99	99
6	94	96	94	93	94	94	92	95	92	95
LSD (*P* = 0.05) = 10.7										
Accelerated aging test (AAT)										
	Germination (%)									
3	0	8	9	36	0	73	76	66	73	50
4	10	13	15	21	6	98	95	89	76	98
5	95	98	97	94	98	100	99	100	99	100
6	40	53	46	48	39	64	74	75	64	64
LSD (*P* = 0.05) = 13.8										

[1] Within each test, significant difference is indicated when the difference between any two means exceeds the LSD value at *P* = 0.05.

[2] In irrigated plots, physical maturity (PM) occurred about 4 weeks after anthesis. Harvest maturity (HM) occurred about 5 weeks after anthesis.

[3] In non-irrigated plots, physical maturity (PM) occurred between 3 and 4 weeks after anthesis. Harvest maturity (HM) occurred slightly more than 4 weeks after anthesis.

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BORON EFFECTS ON RED CLOVER SEED PRODUCTION AND QUALITY

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

Introduction

Boron (B) is a critical micronutrient for many small-seeded legume crop species, including alfalfa and clovers grown for seed. Under mild to moderate B deficiency, legume growth and development may not be severely affected, but seed yield may be reduced (Mozafar, 1993). Boron is required for reproduction, and a deficiency adversely affects the formation of terminal growing points and flowering. When B is deficient, plants produce fewer flowers, and seed production may be inhibited due to inadequate pollination.

Red clover seed yields in western Oregon typically range from 500 to 1,200 lb/acre. Seed production is dependent on the formation of functional flowers, successful fertilization, and conditions suitable for seed development. Year-to-year yield variability is frequently attributed to annual differences in soil moisture availability and/or flower pollination.

Pollination studies showed that native western Oregon bumblebee species are abundant and play an important role in pollinating red clover flowers (Rao and Stephen, 2009). There is increasing evidence that illustrates the equally significant role that B plays in flower fertilization and increased seed yield in leguminous crops. Stigma receptivity and pollination are considered to be the processes most affected by B deficiency. Applications of B to clover have been reported to make flowers more attractive to pollinating insects by increasing nectar production and sugar content, thus improving flower fertilization (Eriksson, 1979). Subterranean clover research has indicated B concentration in plant tissue increased seed production more than did the presence of bees (Ben-Taamallah, 1987).

The total number of flowers produced by plants may also be increased by B fertilization. A foliar B application during early anthesis on alfalfa grown for seed increased seed yield 37% by increasing the number of pods produced. In addition, B applications significantly increased seed germination and seed vigor (Dordas, 2006).

Soils in western Oregon are commonly B deficient, containing less than 1 ppm B. Growers and crop advisors lack research-based agronomic information to assist in making management decisions regarding B fertilizer applications in red clover seed crops. The objectives of this two-year study were to (1) measure seed yield response to B application at different rates and timings and (2) determine the effect of B application on seed quality, including seed germination and seed vigor.

Materials and Methods

This study was initiated in the fall of 2011 at OSU's Hyslop Research Farm on a Woodburn silt loam soil with a pH of 6.2. The preplant soil test B level was 0.4 ppm across the trial, well below the recommended soil test level (1.0 ppm) for red clover seed production in western Oregon (Gardner et al., 2000). The experimental design was a randomized complete block with three replications. Individual plot size was 11 feet x 50 feet. Treatments applied in year 1 were repeated on the same plots in year 2. Soil samples from a 6-inch depth were collected from each individual plot prior to applying B treatments in year 2. In these samples, B levels ranged from 0.3 to 0.4 ppm across all treatments.

Grass and broadleaf weeds were managed with common herbicides registered for use on clover grown for seed in Oregon. In year 1, the trial was flail mowed in mid-May, and residue was left on the field. In year 2, the trial was flail mowed, and the residue was removed from the field. After regrowth, one insecticide application was made to all plots at bud emergence to manage aphids and other insect pests. Honeybee hives were placed near the study site after insecticide applications were complete.

Boron utilized for both foliage and soil application was a water-soluble sodium borate formulation (SprayBor®). Treatments were applied with a bicycle sprayer equipped with TeeJet XR 8003 nozzles at 20 psi applying a spray volume of 18.5 gpa.

Treatments evaluated in both years of the study included:

(1) Control (no B applied)
(2) 1 lb B/acre soil applied in the fall
(3) 2 lb B/acre soil applied in the fall
(4) 1 lb B/acre foliar applied at bud emergence in summer
(5) 1 lb B/acre soil applied in the fall plus 1 lb B/acre foliar applied at bud emergence in summer

Plots were sampled for total above-ground biomass and B tissue concentration at three timings: mid-June prior to foliar B applications, full bloom, and one to three days prior to swathing. Samples were taken from one-square-foot areas at three locations within each plot.

Seed was harvested with a small-plot swather (modified JD 2280) and a Hege 180 small-plot combine. Seed samples were then processed with a M2-B Clipper cleaner, and clean seed yield was determined. Seed weight was measured by counting two 1,000-seed subsamples from cleaned seed samples and determining the weight.

Seed quality analyses were conducted on clean seed samples from 2013 at the OSU seed lab. Seed viability was determined by standard germination tests. Seed vigor was ascertained by cold test and accelerated aging tests (AAT). Germination, hard seed, and viability percentages were recorded. All seed quality tests were conducted using the protocols of the Association of Official Seed Analysts (AOSA, 2012; AOSA, 2009).

Results and Discussion

Soil test analyses from both years indicate a B deficiency was present in the experimental red clover seed fields (data not shown). This deficiency could be corrected by application of B fertilizer. Boron fertilizer increased plant tissue B concentrations when applied to foliage in summer, while no increase in plant tissue B resulted from soil applications in the fall (Tables 1 and 2).

The observed increase in plant tissue B concentration from foliar applications in the summer did not influence seed yield, despite soil test results that suggested a B deficiency was present (Tables 1 and 2). In addition, no statistically significant differences in seed weight or percent cleanout were measured between B application

Table 1. Effect of rate and timing of B fertilizer treatment on seed yield and other characteristics of red clover seed crops in 2012.

B treatment[1]	Yield	Cleanout	Seed wt.	Jun 14 biomass[2]	Jul 14 biomass	Aug 14 biomass	Jun 14 tissue B	Jul 14 tissue B[2]	Aug 14 tissue B[2]
	(lb/a)	(%)	(mg)	(g/ft^2)			(ppm)		
Check	796	2.8	1.691	44.4 ab	153.1	121.0	27.8	22.6 a	23.7 a
Fall 1 lb/a	800	3.4	1.676	45.9 ab	134.3	114.3	29.0	19.3 a	22.8 a
Fall 2 lb/a	782	2.5	1.703	50.5 b	137.0	173.3	28.6	22.1 a	22.2 a
Summer 1 lb/a	725	2.9	1.751	39.7 a	159.0	150.5	27.7	37.4 b	37.0 b
Fall 1 lb/a + Summer 1 lb/a	797	3.4	1.717	51.6 b	145.9	131.2	27.4	52.6 c	37.7 b

[1] Summer applications were foliar applied at bud emergence. Fall applications were soil applied.
[2] Means followed by the same letter are not significantly different from each other at LSD (0.05).

Table 2. Effect of rate and timing of B fertilizer treatment on seed yield and other characteristics of red clover seed crops in 2013.

B treatment[1]	Yield	Cleanout	Seed wt.	Jun 14 biomass	Jul 14 biomass	Aug 14 biomass	Jun 14 tissue B	Jul 14 tissue B[2]	Aug 14 tissue B[3]
	(lb/a)	(%)	(mg)	(g/ft^2)			(ppm)		
Check	707	2.5	1.719	50.2	101.4	91.3	25.4	27.7 a	32.3 a
Fall 1 lb/a	661	2.6	1.783	59.7	102.4	97.6	26.0	24.7 a	25.9 a
Fall 2 lb/a	670	2.3	1.764	59.1	108.3	95.4	24.1	24.8 a	30.1 a
Summer 1 lb/a	636	2.5	1.744	58.4	107.2	94.3	24.7	65.3 b	35.2 ab
Fall 1 lb/a + Summer 1 lb/a	684	3.2	1.731	49.9	95.2	90.1	24.4	56.6 b	43.0 b

[1] Summer applications were foliar applied at bud emergence. Fall applications were soil applied.
[2] July 14 tissue B: Means followed by the same letter are not significantly different from each other at LSD (0.05).
[3] August 14 tissue B: Means followed by the same letter are not significantly different from each other at LSD (0.10).

Table 3. Effect of rate and timing of B fertilizer treatment on seed quality characteristics of red clover seed crops in 2013.[1]

	Germination test			Cold test			AAT
Treatment	Germ.	Hard seed	Total viable seed	Germ.	Hard seed	Total viable seed	Germ.
	(%)						
Check	69	26	95	75	20	95	48
Fall 1 lb/a	66	28	94	66	24	90	51
Fall 2 lb/a	70	24	94	74	17	91	54
Summer 1 lb/a	68	27	95	73	20	93	47
Fall 1 lb/a + Summer 1 lb/a	64	29	93	73	18	91	50

[1] No significant difference was found at LSD (0.05).

rates or application timing treatments. Some transient effects on total above-ground biomass were noted early in 2012, but these effects were not attributable to rate or timing of B fertilizer in either year.

There were no statistically significant differences among treatments in any of the seed quality analyses (Table 3). The B deficiency as determined by soil test analysis did not have any measurable effects on seed quality as measured by viability and vigor tests, and there were no seed quality responses of red clover seed to applied B fertilizers.

The results of this study suggest that red clover seed crops are not adversely affected by B soil test levels in the range of 0.3 to 0.4 ppm as previously thought and that the 1.0 ppm level for taking action to correct a B deficiency may need to be revised. Future work is warranted to better define the soil test level for B deficiency in red clover, as the seed crop was not sensitive to soil test levels as low as 0.3 ppm in the two years of this study. Results indicate that present recommendations for B fertilizer applications may not be economically beneficial in increasing red clover seed yield or improving seed quality in western Oregon.

Acknowledgment

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SURVEY OF WEED SEED CONTAMINANTS IN WESTERN OREGON CLOVER PRODUCTION

N.P. Anderson and A.G. Hulting

Introduction

It is estimated that over 85% of clover seed produced in the United States is grown in Oregon, primarily in the Willamette Valley. Current commodity data indicates that 11,340 acres of crimson clover, 14,180 acres of red clover, and 10,150 acres of white clover were harvested for seed in Oregon in 2013 (OAIN, 2014). The remaining U.S. acreage is primarily located in other northern regions of Oregon, Washington, and Idaho.

Effective weed management in seed production fields is important for maximizing seed yield potential and quality. Seed yield losses occur from either direct weed competition in the field and/or during seed cleaning. As new weed management strategies are developed for clover seed production in Oregon, it is important to understand which weed species cause the most clean seed loss—and subsequent economic loss—during the seed conditioning process.

The objective of this survey project was to develop a practical summary of weed seed occurrence in Oregon clover seed lots, based on interviews conducted with personnel at clover seed cleaning facilities in western Oregon. This information will be useful to both field consultants and growers who make field management decisions and to Extension and other research scientists who conduct weed management research in clover seed crops.

Materials and Methods

In the winter of 2013–2014, surveys were conducted at 12 clover seed conditioning facilities in western Oregon. Of these facilities, five handle crimson clover, six handle red clover, and five handle white clover. The personnel at the facilities were asked to list specific weed species that are commonly found in harvested seed lots. They were then asked to indicate which of these species are relatively easy to clean out, generally difficult to clean out, or sometimes cannot be completely cleaned out.

Results and Discussion

Results from this study (Table 1) indicate that a diverse range of weed seed contaminants can occur in harvested seed lots. The most common weed seed contaminants across all clover species were broadleaf species, including dock species, Brassica species, and small-seeded vetches. In addition, annual grass weed seed contaminants, in particular *L. multiflorum* and *P. annua*, were reported to be an increasing problem in all clover species.

Small-seeded vetches (e.g., *V. hirsute*, *V. tetrasperma*) were consistently noted as the primary contaminant in crimson clover seed lots. Buckhorn plantain (*P. lanceolata*) was reported to be one of the most common “difficult”-to-clean weed species in red clover seed lots, while curly dock (*R. crispus*) was reported to be very problematic in both red and white clover seed lots.

Maturity of the weed seed was reported to be an important factor in the ability to separate out seeds during cleaning. Depending on the clover species, smaller immature weed seeds or larger mature weed seeds may or may not be easy to clean out with standard equipment. For example, it was reported that mature catchweed bedstraw (*G. aparine*) is easier to clean out of a red clover seed lot than an immature seed of the same species, which can be very difficult to clean out. Additional information gleaned by the survey indicates the importance of utilizing various types of seed cleaning equipment in order to effectively separate specific weed species that tend to be problematic in clover seed lots. It was noted that clover seed is generally much more difficult to clean than grass seed. Various pieces of specialized equipment, including air screen cleaners, indent separators, gravity decks, and velvet rollers, must be utilized to adequately clean clover seed lots. Each cleaning facility may contain different types of cleaning equipment, and this will affect its ability or ease in cleaning certain species.

Acknowledgments

Appreciation is extended to Berger Seed Company, Behrman Farms, Cala Farms, Carlton Seed Company, Jewett Cameroon Seed Company, K & K Farms, L3 Farms, Marion Ag Service, Mid-Valley Farms, Scharf Farms, and Vandyke Seed Company for their participation in this survey project.

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Table 1. A summary of weed species reported in harvested clover seed lots by seed conditioning facilities in western Oregon.

	Commonly found in harvested seed lots	Most difficult to clean	Sometimes cannot be cleaned	Easier to clean
Crimson	Small vetches (tiny, narrowleaf, sparrow, four seed), cutleaf geranium, catchweed bedstraw, wild Brassicas (radish, mustard), poison hemlock, toadflax, dogfennel, wild carrot, annual ryegrass	Small vetches Catchweed bedstraw Wild Brassicas Cutleaf geranium	Small vetches Cutleaf geranium	Dogfennel Nipplewort Wild carrot Annual ryegrass
Red	Curly dock, buckhorn plantain, wild Brassicas (radish, mustard), dodder, Canada thistle, dogfennel, mallow, wild carrot, catchweed bedstraw, sharppoint fluvelin, annual ryegrass	Buckhorn plantain Curly dock Wild Brassicas Dodder	Buckhorn plantain Catchweed bedstraw (immature) Dodder	Wild carrot Dogfennel Prickly lettuce Nipplewort Canada thistle Catchweed bedstraw (mature) Sharppoint fluvelin Annual ryegrass
White	Mayweed chamomile, curly dock, pigweed, knotweed, lambsquarter, sowthistle, Canada thistle, witchgrass, chickweed, hop clover, prickly lettuce, catchweed bedstraw, annual bluegrass	Curly dock Lambsquarter Pigweed Dogfennel Thistles	Curly dock	Prickly lettuce Nipplewort Some thistles Hop clover Annual bluegrass

LONG-TERM EFFECTS OF TILLAGE AND ESTABLISHMENT SYSTEMS ON SEED YIELD OF ANNUAL RYEGRASS

T.G. Chastain, W.C. Young III, C.J. Garbacik, and M.E. Mellbye

Introduction

Annual ryegrass was grown on 125,790 acres in Oregon in 2013, making it one of the most widespread seed crops in the state. The acreage of annual ryegrass has been among the most stable of the grass seed crops over the past 35 years, and this crop is an important contributor to the economic welfare of Oregon seed producers. But this stability and need for a crop on low-productivity soils means that annual ryegrass has been grown on some land continuously for decades without rotation.

Long-term annual ryegrass cropping systems trials were initiated in the 2005–2006 crop year by former OSU Extension agent Mark Mellbye. His vision was for a 9-year project to study the long-term effects of several cropping practices on annual ryegrass seed production. While there are several long-term cropping systems practices studies in field crops such as wheat at a variety of locations around the world, no long-term studies in grass seed crops, and annual ryegrass in particular, have been conducted.

In this article, we will examine the long-term effects of cropping systems practices on seed yield in annual ryegrass through year 8.

Methods

Trials have been conducted at the long-term study site located on OSU's Hyslop Farm for the past eight years. 'Gulf' annual ryegrass has been used throughout the study. The experimental design for the trials is a randomized complete block with three replications of the following six tillage and crop establishment systems:

1. Continuous conventional tillage (CT)
2. Continuous no-till (NT)
3. NT/CT cycle (alternate-year tillage)
4. Volunteer/CT cycle (alternate-year tillage)
5. Burn + NT/CT cycle (alternate-year tillage)
6. Volunteer/NT/CT cycle (tillage every third year)

Each of the plots was 25 feet x 125 feet. Conventional tillage involved primary tillage by moldboard plow followed by disking and other secondary tillage operations as needed to produce a seedbed for planting. No-till planting of the annual ryegrass crop was made with a Great Plains no-till drill. The same drill was used to plant the CT stands, although with different settings. In the volunteer treatment, seed shed from the previous crop was the source of seed for establishment of the stand, and rows were created by row-spray removal of approximately 75% of the stand. No tillage was done in the volunteer treatment.

Tillage, residue chopping, herbicide applications, fertilizer applications, and other field activities were conducted according to OSU recommendations and standard grower practices. Crop residues were flail-chopped but not removed from plots. In the burn and NT treatment, residues were not flailed prior to burning.

Seed was harvested with a small-plot swather (modified JD 2280) and threshed with a Hege 180 small-plot combine. Harvested seed was processed through an M2-B Clipper cleaner, and clean seed yield was determined.

Seed weight was measured by using an electronic seed counter to count two 1,000-seed samples from harvested, cleaned seed material and determining the weight on a laboratory balance. Seed number was calculated based on seed yield and 1000-seed weight values obtained from each plot.

Results and Discussion

After eight years of the trials, significant differences among the tillage and stand establishment system practices are emerging (Table 1). Results to date indicate that the lowest seed yields were observed when continuous NT practices were employed. Seed yield in continuous NT was 15% lower than in continuous CT, the predominant system employed by Valley annual ryegrass seed growers. In fact, over the eight-year period, the loss in seed yield in the continuous NT plots was 1,632 lb/acre. Thus, a grower employing continuous NT would have lost a bit more than one year of seed yield over the period as compared to continuous CT.

Increasing the frequency of tillage in the system from zero in the continuous NT plots to once every other year (NT/CT) boosted seed yields so that they were statistically equivalent to yields in the continuous CT plots (Table 1). Alternating volunteer crop

Table 1. Effect of tillage and stand establishment systems for annual ryegrass over an eight-year period on seed production characteristics.

System	Frequency of tillage	Seed production characteristics[1]		
		Seed yield	Seed weight	Cleanout
	(years)	(lb/acre)	(mg)	(%)
Continuous CT	8	1,541 b	3.17 b	2.19 b
Continuous NT	0	1,337 a	3.05 a	2.44 c
NT/CT cycle	4	1,489 b	3.05 a	2.16 ab
Volunteer/CT cycle	4	1,487 b	3.06 a	2.18 b
Burn + NT/CT cycle	4	1,701 c	3.08 a	1.93 a
Volunteer/NT/CT cycle	2	1,491 b	3.04 a	2.29 bc

[1] Means in columns followed by the same letter are not significantly different (*P* = 0.05).

establishment with CT produced seed yields over the eight-year period that were not statistically different from the NT/CT system, without increasing the frequency of tillage. Volunteer and NT establishment had similar effects on seed yield. Volunteer establishment was used in two systems, and NT establishment was used in four systems. The average seed yields in years of volunteer establishment across two systems (1,280 lb/acre) were essentially the same as the average obtained with NT establishment across four systems (1,292 lb/acre). A three-year cycle of volunteer establishment and NT/CT also produced seed yields that were similar to the NT/CT and continuous CT systems, but the frequency of tillage was reduced to once every three years. Disturbance of the residue in preparation of the seedbed in any alternate-year cycle produced an overall increase in seed yield over the continuous NT system.

Highest seed yields over the eight-year period were found in the burn + NT/CT cycle (Table 1). Removal of straw and stubble by burning was accompanied by disturbance of residues in seedbed preparation in the CT portion of the alternate-year cycle. This combination of residue management on an alternate year basis produced an average 10% increase in seed yield over the continuous CT system. The increased seed yield in this system did not primarily come from the burn + NT portion of the cycle (1,563 lb/acre). Rather, the CT portion (yield = 1,839 lb/acre) was greatly improved by having the burn + NT present in the cycle.

The seed yield results attained by the two tillage systems varied with frequency of use (Figure 1). Compared to continuous CT, seed yields were increased by an average of 16% when CT was cycled with NT, volunteer, or burn + NT. On the other hand, seed yields from NT were the same regardless of whether NT was continuous or cycled with other practices. In other words, seed yield of CT was increased by the presence of NT or other practices in the system as part of a farming cycle, but yields of NT were not influenced by CT or other practices in the cycle. Seed yields in NT fields were reduced by slug predation. The best seed yield performance of NT occurred when the practice was coupled with residue burning. These results suggest that a moderate frequency of tillage with disturbance of crop residues and occasional removal of crop residues are required to produce the best seed yield results over time in annual ryegrass cropping systems.

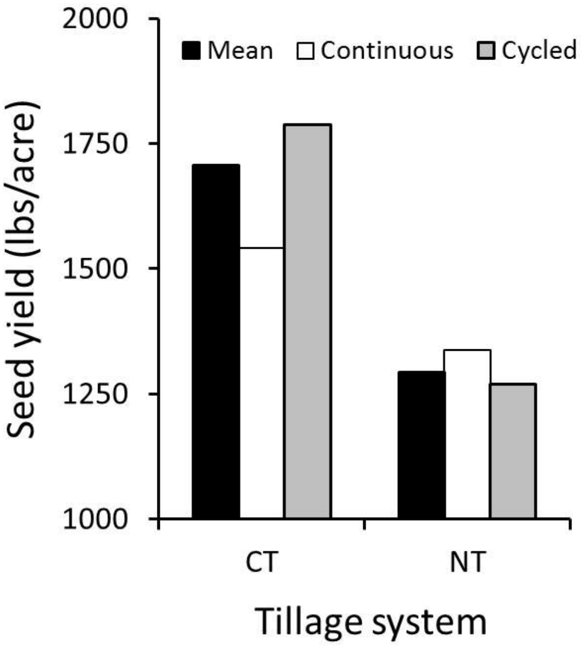

Figure 1. Effect of tillage systems practices (continuous or cycled to other practices) over an eight-year period on seed yield in annual ryegrass.

Seed weight was greatest in the continuous CT system (Table 1). However, the differences observed among the tillage and crop establishment systems tested in this study were primarily attributable to seed number rather than seed weight (Figure 2).

Cleanout is the quantity of non-seed plant material harvested at the time of combining. An increase in cleanout poses an economic hardship for seed growers because this material must be removed in post-harvest conditioning of the seed. Cleanout was lowest in the burn + NT/CT system and greatest with continuous NT (Table 1). These two treatments represent the greatest range of differences in residue disturbance and removal. These differences were reflected most in higher cleanouts of the continuous NT system and to a lesser extent in cleanouts of other systems where burning was not used. Increases in cleanout in the absence of burning may have resulted from a change in partitioning of dry matter to non-reproductive structures that were captured in the harvest process.

Because changes in soil carbon, organic matter, nitrogen, and pH are relatively small each year, the observed differences in the sampled soil profile were also small across tillage and establishment systems. Nevertheless, there were definite trends for increased carbon and organic matter in the continuous NT system over other practices. These effects were most pronounced in the uppermost portion of the soil profile. Anticipated benefits of reduced tillage in annual ryegrass seed production enterprises include improved soil quality and carbon sequestration.

This is the fourth in the series of reports on the long-term effects of tillage and crop establishment systems on annual ryegrass seed production. The fifth and final installment will report how these cropping systems practices affected seed productivity and soil characteristics over the nine-year span of the study.

Acknowledgments
The authors wish to thank the Oregon Ryegrass Growers Seed Commission and the Hyslop Professorship for support of this work.

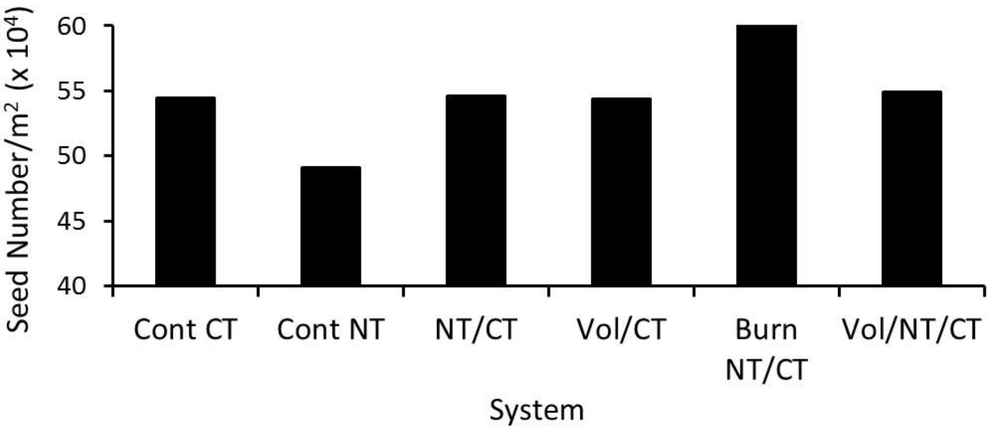

Figure 2. Effect of tillage and establishment systems over an eight-year period on seed number in annual ryegrass.

EVALUATING DESICCANTS FOR AFTER-HARVEST BURN-DOWN IN KENTUCKY BLUEGRASS SEED FIELDS

G. Sbatella and S. Twelker

Introduction

Kentucky bluegrass seed fields can remain in a vegetative state when mild, moist conditions follow harvest. The removal of green biomass is then delayed, affecting development of the crop during the next season. Under these conditions, management of the remaining straw is a challenge to grass seed producers. Desiccants are used as harvest aids in many crops and could facilitate foliar burn-down of grass plants when applied after harvest. This approach would particularly benefit central Oregon seed growers, where burning fields within an eighth of a mile of highways is not allowed. However, there can also be benefits for fields that are burned, including more timely management of crop residues, reduced number of fires required after harvest (due to less remaining residue), and reduced propane burning. These factors can help minimize the amount of smoke produced by field burning.

The herbicide paraquat has been used as a desiccant, but increasing restrictions regarding pesticide residues make the labeling of this product very difficult. A new generation of harvest aids is being applied to other crops, but no information regarding their use or impacts in Kentucky bluegrass seed fields is available. The objective of this study was to evaluate the use of herbicides as desiccants for burn-down in Kentucky bluegrass seed fields with inadequate drying following harvest.

Materials and Methods

Two field studies were conducted in October 2013 on an established Kentucky bluegrass field at COARC, Madras, OR. The study design was a randomized complete block with four replications with a plot size of 12 feet x 25 feet. The treatments consisted of glufosinate (Rely 280®), saflufenacil (Sharpen®), diquat (Reglone®), flumioxazin (Valor®), and propane burner as the comparison standard. Some herbicides tested for burn-down are not currently labeled for use in grasses grown for seed; they were selected because they are being used in other crops as harvest aids.

Environmental conditions following desiccant application differed at the two fields. For instance, conditions after the applications in study “A” can be characterized as cloudy with showers (average daily radiation = 316 Langley/day; total rain = 0.1 inch). At the study “B” field, weather was mostly sunny and dry (average daily radiation = 437 Langley/day; total rain = 0).

Herbicides were applied with a backpack sprayer calibrated to deliver 20 gallons of spray solution per acre at 40 psi pressure using XR 8002 Teejet® nozzles. Application dates and environmental conditions for each study are detailed in Table 1. Herbicide rates and adjuvants are detailed in Table 2. Moisture content from plant tissue was estimated by harvesting plant biomass from a six-square-foot area. Fresh and dry weights of plant samples collected 3, 7, and 10 days after treatment (DAT) were recorded.

Results and Discussion

Since the studies were located adjacent to each other, the differences observed in herbicide performance can be attributed largely to differences in environmental conditions following application.

Diquat applied at 2 pt/acre reduced percent moisture in plant tissue regardless of the environmental conditions after spraying, although effects were more rapid with cloudy weather and rain showers. The percent moisture in plant biomass in study “A” was reduced quickly with diquat and was evident 3 DAT (Table 2). The moisture reduction recorded for the application of diquat was comparable to the use of propane burner. Moisture content steadily increased in the following days, reaching 48% for diquat 10 DAT. Nevertheless, this moisture content remained the lowest among the tested desiccants in study “A”.

Table 1. Application date and environmental conditions for herbicide applications.

	Study “A”	Study “ B”
Application date	10/3	10/10
Time of day	11 am	9 am
Air temperature (°F)	46	41
Relative humidity (%)	70	82
Wind speed (mph)	3	3
Wind direction	W	SW
Average daily radiation, 10 DAT[1]	316 L/d	437 L/d
Accumulated rainfall, 10 DAT	0.1 inch	0

[1] DAT = days after treatment

In study “B” (sunnier and drier conditions after application), diquat at 2 pt/acre and glufosinate at 3.5 pt/acre effectively reduced plant moisture similarly to the use of propane burner, but the reduction was only noticeable 10 DAT.

Although some herbicides used as desiccants were effective in reducing the percent moisture in plant tissue, they had no impact on the total biomass produced (Table 3). This fact should be taken into consideration if biomass reduction is a management objective.

In conclusion, some herbicides have the potential for use in burn-down of Kentucky bluegrass grown for seed. Their performance will depend not only on the active ingredient used, but also on environmental conditions following application. Nevertheless, none of these alternatives will have the same impact on plant biomass seen with the use of a propane burner.

Acknowledgments
The authors thank Hoyt Downing and Mitchell Alley for their collaboration on this project.

Table 2. Plant biomass percent moisture for each treatment, 3, 7, and 10 days after treatment.

			--------------------- Plant biomass % moisture[1,2] ---------------------					
			---------- Study “A” -----------			---------- Study “B” -----------		
Treatment[3,4]		Rate	3 DAT	7 DAT	10 DAT	3 DAT	7 DAT	10 DAT
1	Glufosinate Ammonium sulfate	3.5 pt/a	58 a	60 a	57 a	57 ab	77 a	39 b
2	Saflufenacil MSO Ammonium sulfate	4 fl oz/a	58 a	57 a	60 a	58 a	76 a	55 a
3	Diquat NIS	2 pt/a	39 b	40 b	48 b	51 b	80 a	37 b
4	Flumioxazin MSO	3 oz/a	58 a	58 a	60 a	57 ab	74 a	51 a
5	Propane burner	—	31 b	34 b	42 b	34 c	27 b	34 b
	Untreated check	—	59 a	59 a	60 a	55 ab	75 a	51 a
LSD ($P = 0.05$)								

[1] DAT = days after treatment

[2] Means within columns followed by the same letter are not different at $P = 0.05$.

[3] MSO = methylated seed oil; NIS = nonionic surfactant

[4] Some treatments included in the study were used for experimental purposes and are NOT currently labeled for public use. Before using an herbicide, make certain it is properly labeled for the intended use.

Table 3. Average dry biomass 10 days after treatment.

Treatment[2,3]		Rate	---- Dry biomass[1] ----	
			Study “A”	Study “B”
			--------- (lb/a) ----------	
1	Glufosinate Ammonium sulfate	3.5 pt/a	609 a	449 a
2	Saflufenacil MSO Ammonium sulfate	4 fl oz/a	641 a	513 a
3	Diquat NIS	2 pt/a	545 a	481 a
4	Flumioxazin MSO	3 oz/a	641 a	609 a
5	Propane burner	—	192 b	64 b
	Untreated check	—	577 a	513 a
LSD (*P* = 0.05)			224	—

[1] Means within columns followed by the same letter are not different at *P* = 0.05.

[2] MSO = methylated seed oil; NIS = nonionic surfactant

[3] Some treatments included in the study were used for experimental purposes and are NOT currently labeled for public use. Before using an herbicide, make certain it is properly labeled for the intended use.

MEDUSAHEAD CONTROL WITH APPLICATIONS OF PRE- AND POST-EMERGENT HERBICIDES IN KENTUCKY BLUEGRASS GROWN FOR SEED

G. Sbatella and S. Twelker

Introduction

Because of their morphological and physiological similarities, it is difficult to control annual grasses within a field of perennial grasses. The persistence of annual grass infestations results in a perpetual loss of yield. Medusahead (*Taeniatherum caput-medusae***)** is a ubiquitous invader of rangelands and pastures, and recent reports indicate that this annual grassy weed species is present in Kentucky bluegrass (KBG) seed production fields in central Oregon. The presence of medusahead raises concerns among producers because it has the potential to reduce yields and affect seed quality.

The best way to address the medusahead problem is an integral approach that combines practices that promote healthy, vigorous stands of KBG; prevention of weed seed dispersal to production fields; and a weed control program that includes herbicides. The use of pre- and post-emergent herbicides is critical for the success of an integral approach since herbicides can either prevent seedling emergence or provide control of emerged plants growing on infested fields.

Obtaining a label for a new herbicide is costly and requires time. Therefore, testing herbicides already labeled for use in KBG for their effectiveness in medusahead control is a priority. Field studies were conducted at the Central Oregon Research Center (COARC) in Madras, OR, to evaluate pre- and post-emergent herbicides labeled for use in established stands of KBG for their efficacy in medusahead control.

Materials and Methods

Two field studies looking at pre- and post-emergent herbicides for medusahead control were conducted in the fall of 2012 and spring of 2013. The studies were conducted on an established Kentucky bluegrass field at COARC. The study design was a randomized complete block with four replications. Plot size was 10 feet x 30 feet. Medusahead seeds were planted inside a permanent six-square-foot quadrant to ensure weed infestation in all plots.

Pre-emergent herbicides were applied in the fall of 2012. Treatments consisted of dimethenamid (Outlook$^®$), mesotrione (Callisto$^®$), ethofumasate (Nortron$^®$), oxyflourfen (Goal 2 XL$^®$), pendimethalin (Prowl $H_20^®$), terbacil (Sinbar$^®$), and metolachlor (Dual Magnum$^®$). Following herbicide application, the study area was irrigated for soil incorporation of the herbicide. Post-emergent treatments were applied to medusahead plants with two fully expanded true leaves in the spring of 2013. Herbicides used were primisulfuron (Beacon$^®$), metribuzin (Sencor 75DF$^®$), dicamba, flufenacet + metribuzin (Axiom$^®$), flucarbazone (Everest$^®$), and mesotrione (Callisto$^®$). All herbicides were applied with a backpack sprayer calibrated to deliver 20 gallons of spray solution per acre at 40 psi pressure using XR 8002 Teejet$^®$ nozzles. Application dates and environmental conditions are detailed in Table 1. Rates and adjuvants for pre-emergent herbicides are detailed in Table 2 and for post-emergent herbicides in Table 3. Herbicide efficacy of pre-emergent herbicides applied in the fall was determined in the spring of 2013. Post-emergent applications were evaluated 30 days after application.

Table 1. Application date and environmental conditions at time of herbicide applications.

	Pre-emergent	Post-emergent
Application date	10/2/12	4/18/13
Time of day	9 am	9 am
Air temperature (°F)	57	47
Relative humidity (%)	54	54
Wind speed (mph)	6	3
Wind direction	SSE	WNW

Results and Discussion

Control with pre-emergent herbicides

Among the tested pre-emergent herbicides, three stood out for their effectiveness in medusahead control. Outlook (21 fl oz/acre), Callisto (6 fl oz/acre), and Nortron (3 qt/acre) provided 90, 88, and 99% percent control, respectively (Table 2). In contrast, no medusahead control was observed with a pre-emergent application of Goal 2XL, Prowl H_20, Sinbar, or Dual Magnum. No visible crop injury was observed after herbicide application.

Control with post-emergent herbicides

Medusahead control provided by all tested post-emergent herbicides was poor, and none provided commercially acceptable control (Table 3). The most effective herbicide was Sencor 75DF (0.5 lb/a), but it provided only 31% control.

Results from these studies suggest that a few pre-emergent herbicides currently labeled for use in Kentucky bluegrass can prevent medusahead establishment. Once medusahead plants get established, control with post-emergent herbicides is not an alternative with the available labeled herbicides. The limited options for medusahead control with labeled herbicides emphasize the need to implement an integral management program that includes cultural practices that ensure vigorous stands of Kentucky bluegrass grown for seed, efforts to prevent seed dispersal, and other weed management practices. Our studies should be repeated to confirm results and explore other alternatives for medusahead control.

Acknowledgment
The authors thank Tim VanDomelen for his collaboration on this project.

Table 2. Medusahead percent control with pre-emergent herbicides compared to untreated checks.[1]

No.	Treatment	Rate	Control[2]
			(%)
1	Outlook®	21 fl oz/acre	90 b
2	Callisto®	6 fl oz/acre	88 b
3	Nortron®	3 qt/acre	99 b
4	Goal 2 XL®	3 fl oz/acre	0 a
5	Prowl H_20®	3 qt/acre	0 a
6	Sinbar®	1 lb/acre	0 a
7	Dual Magnum®	21 fl oz/acre	0 a
	Non-treated check	—	0 a
LSD (*P* = 0.05)			8

[1] Pre-emergent herbicides applied in fall 2012. Efficacy evaluated in spring 2013.
[2] Means among columns followed by the same letter are not different at *P* = 0.05.

Table 3. Medusahead percent control with post-emergent herbicides compared to untreated checks.[1]

No.	Treatment[2]	Rate	Control[3]
			(%)
1	Beacon®	0.75 oz/a	19 a
	MSO	1% v/v	
	Ammonium sulfate	2% v/v	
2	Sencor 75DF®	0.5 lb/a	31 a
	NIS	0.25% v/v	
	Ammonium sulfate	2% v/v	
3	Dicamba®	2 qt/a	0 b
	NIS	0.25% v/v	
	Ammonium sulfate	2% v/v	
4	Axiom®	10 oz/a	19 a
	NIS	0.25% v/v	
	Ammonium sulfate	2% v/v	
5	Everest 70 WDG®	0.85 oz a	13 ab
	NIS	0.25% v/v	
	Ammonium sulfate	2% v/v	
6	Callisto®	6 fl oz/a	13 ab
	NIS	0.25% v/v	
	Ammonium sulfate	2% v/v	
7	Non-treated check	—	0 b
	LSD (*P* = 0.05)		18

[1] Efficacy evaluated 30 days after post-emergent herbicide application.
[2] MSO = methylated seed oil; NIS = nonionic surfactant
[3] Means among columns followed by the same letter are not different at *P* = 0.05.

VOLUNTEER WHEAT CONTROL IN NEWLY SEEDED KENTUCKY BLUEGRASS GROWN FOR SEED

G. Sbatella and S. Twelker

Introduction

Crop rotation in central Oregon often involves planting perennial grass for seed in August following wheat harvest. Wheat grain losses occur before and during harvest. As a result, wheat seeds remain in the soil and become the source of volunteer plants in the next crop. Volunteer wheat plants compete with the perennial grass crop for light, nutrients, and water, similar to any other weed. Competition from volunteer wheat can affect grass seed yield and quality and even compromise establishment of new grass stands. Control of annual grasses growing in competition with perennial grasses is difficult due to morphological and physiological similarities that drastically limit herbicide control options. Management options are further restricted due to the limited alternatives available for control in newly planted perennial grass. These management complexities and the resulting crop losses make determining the control efficacy of volunteer wheat and potential crop injury of currently labeled options a high priority.

Materials and Methods

A field study was conducted in September 2012 to evaluate volunteer wheat control on a newly planted Kentucky bluegrass field at COARC, Madras, OR. The study design was a randomized complete block with four replications with a plot size of 10 feet x 30 feet. Treatments consisted of ethofumasate (Nortron®), mesotrione (Callisto®), and primisulfuron (Beacon®). Nortron and Callisto were applied pre-emergent and early post-emergent, while primisulfuron was applied early post-emergent and in two sequential post-emergent applications. Herbicides were applied with a backpack sprayer calibrated to deliver 20 gallons of spray solution per acre at 40 psi pressure using XR 8002 Teejet® nozzles. Application dates and environmental conditions for each study are detailed in Table 1. Herbicide rates and adjuvants are detailed in Table 2. Herbicide efficacy and crop injury were evaluated in spring of 2013. Plots were harvested in 2013 to determine the impacts of each treatment on grass seed yield.

Table 1. Application date and environmental conditions for herbicide applications.

Application timing	A	B	C
Application date	9/28	11/2	11/22
Time of day	9 am	10 am	11 am
Air temperature (°F)	68	42	44
Relative humidity (%)	31	80	56
Wind speed (mph)	2	2	5
Wind direction	SSE	NW	NE

Results and Discussion

Volunteer wheat control and crop injury

Volunteer wheat control and crop injury differed among treatments and time of application (Table 2). For instance, control with Nortron applied at pre-emergent was excellent (98%), but crop injury was significant (38%). Kentucky bluegrass injury was reduced to 18% when Nortron was applied early post-emergent, but only 10% of the volunteer wheat was controlled. The application of Callisto at pre-emergent resulted in only 5% control of volunteer wheat and crop injury of 3%. Control with Callisto improved to 68 and 59% when Callisto was applied early post-emergent at rates of 3 and 6 fl oz/acre, respectively. No crop injury was observed for this treatment the following spring. Beacon applied early post-emergent at 0.76 oz/acre, or in sequential applications of 0.38 oz/acre each, provided 92 and 97% volunteer wheat control, respectively. Nevertheless, a high level of crop injury was observed with these treatments the following spring.

Kentucky bluegrass seed yield

Although Nortron and Beacon treatments provided high levels of volunteer wheat control, these herbicides were associated with elevated crop injury that resulted in lower seed yields (Table 2). Callisto at 3 or 6 fl oz/acre provided only partial volunteer wheat control (68 and 59%, respectively). However, this partial control, combined with low crop injury, resulted in seed yields of 167 and 155 lb/acre, the highest among all treatments.

Results from this study indicate that volunteer wheat control in newly established stands of Kentucky bluegrass grown for seed with labeled herbicides is difficult because the most effective treatments cause unacceptable levels of crop injury, while levels of control provided by the safest products are not commercially acceptable. The levels of control and crop injury observed with the use of herbicides emphasize the need to implement an integral management program that includes cultural practices that ensure vigorous stands of Kentucky bluegrass as well as reduction of wheat seed losses during harvest.

Acknowledgment
The authors thank Tim VanDomelen for his collaboration on this project.

Table 2. Percent volunteer wheat control, crop injury, and Kentucky bluegrass seed yield for herbicide treatments tested in Madras, OR.

No.	Treatment[1,2]	Rate	Code[3]	Control[4]	Injury[4]	Yield[4]
				(%)	(%)	(lb/a)
1	Nortron®	3 pt/a	A	98 a	38 b	91 bc
2	Nortron®	3 pt/a	B	10 c	18 c	34 c
3	Callisto®	6 fl oz/a	A	5 c	3 c	86 bc
4	Callisto® COC Ammonium sulfate	3 fl oz/a 1% v/v 8.5 lb/100 gal	B	68 b	0 c	167 a
5	Callisto® COC Ammonium sulfate	6 fl oz/a 1% v/v 8.5 lb/100 gal	B	59 b	0 c	155 ab
6	Beacon® COC	0.76 oz wt/a 1% v/v	B	92 a	40 b	88 bc
7	Beacon® COC Beacon® COC	0.38 oz wt/a 1% v/v 0.38 oz wt/a 1% v/v	B C	97 a	60 a	42 c
8	Untreated check	—	—	0 c	0 c	67 c
LSD ($P = 0.05$)				15	16	55

[1] Before using an herbicide, make certain it is properly labeled for the intended use.
[2] COC = Crop oil concentrate
[3] A = pre-emergent; B = early post-emergent; C = 20 days after B
[4] Means among columns followed by the same letter are not different at *P* = 0.05.

GRASS WEED MANAGEMENT IN ESTABLISHED PERENNIAL RYEGRASS GROWN FOR SEED

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

Introduction

Weed management studies were conducted over a two-year period (2011–2013) at the Oregon State University Hyslop Research Farm. The objective was to evaluate the efficacy and potential for crop injury from pre-emergent herbicide treatments applied as a management strategy for the control of roughstalk bluegrass (*Poa trivialis*), California brome (*Bromus carinatus*), and diuron-resistant annual bluegrass (*Poa annua*) in established perennial ryegrass grown for seed.

Materials and Methods

For the 2011-2012 study, soils at the research farm sites were Woodburn silty clay loams with a pH of 6, 2.32% organic matter (OM), and a cation exchange capacity (CEC) of 15.8. For the 2012–2013 study, soils had a pH of 5.5, 2.52% OM, and a CEC of 15.4.

The experimental design of both studies was a randomized complete block with four replications. In 2011–2012, the established perennial ryegrass stand was planted with the variety 'Prelude IV'. Three rows of diuron-resistant *P. annua* and three rows of *B. carinatus* were planted in fallow areas in the front portion of each plot prior to the pre-emergent applications. In 2012–2013, the established perennial ryegrass stand was planted with the variety 'Silver Dollar'. Three rows of diuron-resistant *P. annua* and three rows of *P. trivialis* were planted in fallow areas in the front portion of the plots. In both years, the seeded rows of weeds varied slightly in planting depth, leading to staggered emergence of the two species.

Herbicides were applied pre-emergent (Tables 1 and 2) or as a combination of a pre-emergent application followed by a second application applied 35 days later (Tables 3 and 4). Pre-emergent treatments were applied on October 20, 2011, the day following planting of the *B. carinatus* and the diuron-resistant *P. annua* as described above. Treatments were applied with a research sprayer calibrated to deliver 20 gpa at 20 psi. Weed control was evaluated visually. The perennial ryegrass seed was harvested, and clean seed yields were quantified. Data were analyzed using ANOVA and means separated by LSD.

The 2011–2012 study also evaluated tolerance of the established perennial ryegrass 'Prelude IV' to fall applications of pyroxasulfone and pyroxasulfone in combination with flumioxazin. These treatments were compared to industry standard treatments of flufenacet-metribuzin, dimethenamid-P, and s-metolachlor.

Results and Discussion

Results from the 2011–2012 study are shown in Table 1. No visible injury was apparent from any of the treatments on April 11, 2012. No reductions in perennial ryegrass seed yield were quantified following seed cleaning. Yield was lowest from the untreated check treatment, probably due to competition from volunteer perennial ryegrass "sprout."

Pyroxasulfone did not control the *P. annua* adequately at the lowest rate applied, but provided good control (above 90%) at the higher rates. When combined with flumioxazin, control of *P. annua* with the low rate of pyroxasulfone improved from 80% to 89%. Diuron-resistant *P. annua* control was also good with flufenacet-metribuzin and dimethenamid-P. Diuron-resistant *P. annua* control with s-metolachlor was poor.

Pyroxasulfone applied at the highest rate, flufenacet-metribuzin, and dimethenamid-P provided good control of seedling California brome. The addition of flumioxazin improved California brome control when applied with the lowest rate of pyroxasulfone.

In the 2012–2013 study, the pre-emergent herbicides flufenacet-metribuzin, pyroxasulfone, pyroxasulfone-flumioxazin, indaziflam, s-metolachlor, and dimethenamid-P provided 90% or greater control of diuron-resistant *P. annua* on November 9, 30 days following application (Table 2). *P. trivialis* control was greater than 90% except with the indaziflam treatment, which resulted in 85% control.

In May 2013, flufenacet-metribuzin treatments followed by a different herbicide provided 99–100% control of *P. annua* and 94% or greater control of *P. trivialis* (Table 3). A pre-emergent application of dimethenamid-P followed either with flufenacet-metribuzin or indaziflam maintained control of both *Poa* species at greater than 94% through May (Table 4). Dimethenamid-P followed with s-metolachlor was equivalent to dimethenamid-P followed by pendimethalin for *P. annua* control, resulting in 90 and

Table 1. Crop injury and grass weed control (*P. annua* and *B. carinatus*) in established perennial ryegrass, 2011–2012.

Treatment	Rate	Crop injury[1]	*Poa annua*	*Bromus carinatus*	Clean seed yield
	(lb ai/a)	(%)	------- (% control 4/11/2012)	--------	(lb/a)
Check	—	—	—	—	906
Pyroxasulfone	0.05	3	80	68	982
Pyroxasulfone	0.09	0	95	85	987
Pyroxasulfone	0.18	0	100	95	978
Flufenacet-metribuzin	0.43	0	97	95	1,033
Dimethenamid-P	0.98	3	93	91	941
s-metolachlor	0.95	0	49	84	981
Pyroxasulfone + flumioxazin	0.05 0.04	3	89	89	944
Pyroxasulfone + oxyfluorfen	0.05 0.06	0	83	88	1,016
LSD (P = 0.05)[2]	—	NS	19	9	NS
CV	—	—	17	89	—

[1] Crop injury visually assessed on April 11, 2012.
[2] NS = Not statistically different

Table 2. Grass weed control (*P. annua* and *P. trivialis*) and clean seed yield in established perennial ryegrass with pre-emergent herbicide application, 2012–2013.

Treatment	Rate	Timing	*Poa annua*	*Poa trivialis*	*Poa annua*	*Poa trivialis*	Clean seed yield
	(lb ai/a)		(% control 11/9/2012)		(% control 5/31/2013)		(lb/a)
Check	—	—	—	—	—	—	663
Flufenacet-metribuzin	0.425	Pre	100	100	98	89	673
Pyroxasulfone	0.09	Pre	98	100	99	86	791
Indaziflam	0.02	Pre	90	85	91	97	788
Pyroxasulfone-flumioxazin	0.095	Pre	100	100	96	84	634
Pyroxasulfone-flumioxazin	0.143	Pre	100	100	99	94	735
Dimethenamid-P	0.98	Pre	93	98	48	29	646
s-metolachlor	0.95	Pre	90	90	18	8	692
Pendimethalin	2.38	Pre	30	33	0	10	768
LSD (P = 0.05)[1]	—	—	19	20	30	21	NS
CV	—	—	17	18	35	26	—

[1] NS = Not statistically different

91% control, respectively. For control of *P. trivialis*, dimethenamid-P followed by metolachlor (79%) was better than dimethenamid-P followed by pendimethalin (60%). A pre-emergent s-metolachlor application followed by flufenacet-metribuzin, pyroxasulfone, indaziflam or dimethenamid-P maintained control of both *Poa* species at greater than 90%, with the exception of *P. trivialis* control with dimethenamid-P (86%) (data now shown). *P. annua* control remained greater than 90% through May with a single application of flufenacet-metribuzin, pyroxasulfone, indaziflam, or pyroxasulfone-flumioxazin (Table 2). *P. trivialis* control of greater than 90% through May was achieved with single applications of only indaziflam or pyroxasulfone-flumioxazin (Table 2) or by utilizing a combination of a pre-emergent application followed by a different herbicide (Table 3).

Of the currently registered herbicides for use in grasses grown for seed, the flufenacet-metribuzin pre-emergent treatment followed by pendimethalin is the only option that avoids using herbicides in sequence with the same site of action. Sequential applications of herbicides with the same site of action is a practice that is troubling from a resistance management viewpoint. Pyroxasulfone, pyroxasulfone-flumioxazin, and indaziflam are not currently registered for use on grasses grown for seed. However, pyroxasulfone-flumioxazin is in the IR-4 program in an effort to develop labels for use in grasses grown for seed. Indaziflam seems to have utility in grass seed production and would introduce a new mode of action to the cropping system.

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Table 3. Grass weed control (*P. annua* and *P. trivialis*) and clean seed yield in established perennial ryegrass with pre-emergent (flufenacet-metribuzin) and post-emergent herbicide application, 2012–2013.

Treatment	Rate	Timing	*Poa annua*	*Poa trivialis*	*Poa annua*	*Poa trivialis*	Clean seed yield
	(lb ai/a)		(% control 11/9/2012)		(% control 5/31/2013)		(lb/a)
Check	—	—	—	—	—	—	663
Flufenacet-metribuzin fb pyroxasulfone	0.425 0.09	Pre + 35 days	100	100	100	100	791
Flufenacet-metribuzin fb indaziflam	0.425 0.02	Pre + 35 days	95	95	99	100	782
Flufenacet-metribuzin fb dimethenamid-P	0.425 0.98	Pre + 35 days	100	100	100	98	676
Flufenacet-metribuzin fb s-metolachlor	0.425 0.95	Pre + 35 days	100	100	99	94	738
Flufenacet-metribuzin fb pendimethalin	0.425 2.38	Pre + 35 days	100	100	100	95	681
LSD (P = 0.05)[1]	—	—	6	6	2	4	NS
CV	—	—	5	5	2	3	—

[1] NS = Not statistically different

Table 4. Grass weed control in established perennial ryegrass with pre-emergent (dimethenamid) and post-emergent herbicide application, 2012–2013.

Treatment	Rate	Timing	*Poa annua*	*Poa trivialis*	*Poa annua*	*Poa trivialis*	Clean seed yield
	(lb ai/a)		(% control 11/9/2012)		(% control 5/31/2013)		(lb/a)
Check	—	—	—	—	—	—	663
Dimethenamid-P fb flufenacet-metribuzin	0.98 0.425	Pre + 35 days	95	95	98	94	729
Dimethenamid-P fb indaziflam	0.98 0.02	Pre + 35 days	93	95	95	98	746
Dimethenamid-P fb s-metolachlor	0.98 0.95	Pre + 35 days	90	95	90	79	730
Dimethenamid-P fb pendimethalin	0.98 2.38	Pre + 35 days	90	95	91	60	676
Dimethenamid-P + pendimethalin fb pendimethalin	0.98 2.38 1.43	Pre Pre + 35 days	100	100	79	71	739
LSD (P = 0.05)[1]	—	—	9	9	31	22	NS
CV	—	—	7	7	29	24	—

[1] NS = Not statistically different

OCCURRENCE AND TRENDS OF WEED SEED AND PATHOGEN CONTAMINANTS IN BENTGRASS SEED LOTS IN OREGON[1]

S.C. Alderman, S.G. Elias, and A.G. Hulting

Introduction

Nearly all of the bentgrass seed grown in the United States is produced in Oregon as certified seed. However, little is known about the occurrence of weed seed or pathogen propagule contaminants in bentgrass seed lots. Dade (1996) summarized weed contaminants, as recorded in Oregon State University (OSU) Seed Lab records for the years 1986–1995 in a report to the Oregon Seed Council, but the report included raw data and was not published. A portion of the report, describing weed seed contaminants in fine fescue seed lots from seed production fields in Oregon was recently compiled and published (Alderman et al., 2011).

Purity analyses for certified seed lots are conducted at the OSU Seed Lab, as required by the Oregon Seed Certification Program. Seed samples are collected for testing by certified personnel, using standardized sampling protocols to provide a representative sample of each lot, and are submitted as sealed official samples to the OSU Seed Lab. During purity analyses, the sample is separated into four components: pure seed, weed seed, inert matter, and other crops. Ergot and seed galls are recorded as number of pieces and grouped into the inert matter fraction. Each component is determined as a percentage by weight. Weed seed species are identified by experienced seed analysts at the OSU Seed Lab.

The two most common pathogen contaminants found in bentgrass seed are sclerotia of the fungus *Claviceps purpurea*, commonly known as ergot, and galls of the seed gall nematode, *A. agrostis*. In a survey of seed lot samples from 1986 to 1989, the percentage of seed lots of colonial and creeping bentgrass contaminated with ergot ranged from 9 to 30% and 14 to 21%, respectively (Alderman, 1991). In a field survey in the Willamette Valley during 1988, the seed gall nematode was found in 9 out of 45 bentgrass fields examined (Alderman, 1988). In a survey in the Willamette Valley in 1989, the seed gall nematode was found in 5 out of 38 colonial bentgrass fields and 3 out of 37 creeping bentgrass fields examined (Alderman, 1991). It is not known whether levels of these pathogens or weed seed contaminants have changed over the past two decades. This study was conducted to assess the diversity and frequency of occurrence of weed seeds, ergot (*Claviceps purpurea*), and seed galls (*Anguina agrostis*) in colonial (*Agrostis capillaris* L.) and creeping [*Agrostis stolonifera* L. var. *palustris* (Huds.) Farw.] bentgrass certified seed lot samples submitted to the OSU Seed Lab for purity analysis during 1986–1995 and 2002–2010.

Materials and Methods

Source of data

Data for 1986–1995 were obtained and compiled from a summary of weed seed occurrence in certified seed sample purity records at the OSU Seed Lab (Dade, 1996). Data for 2002–2010 were obtained from the OSU Seed Lab purity records for certified seed lots of colonial and creeping bentgrass. The percentage seed lots contaminated with ergot and seed gall was also determined for 2011 and 2012. The OSU Seed Lab purity records list weed seed contaminants by common or scientific names, based on the AOSA *Uniform Classification Handbook of Weed and Crop Seeds* (AOSA, 2011a). Duplicate records associated with retesting of a given bentgrass seed lot were excluded from this analysis.

Purity samples were drawn and prepared for testing according to the AOSA *Rules for Testing Seeds* (AOSA, 2011b). The size of purity sample for bentgrass is 0.25 g (approximately 2,500 seeds). In addition, a total of 2.5 g (approximately 25,000 seeds) were inspected using the "all states noxious weed exam" for the presence of prohibited and/or restricted noxious weed seeds. The test is based on Federal and official State lists of noxious weed seeds. Presence of sclerotia of ergot or seed gall nematode is noted on the purity record. Common and scientific names of weed species used in this report are based on the *Uniform Classification of Weed and Crop Seeds* (AOSA, 2011a) or, for entries missing from that publication, the USDA online Plants Database (http://plants.usda.gov/java/).

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[1] This report is a condensed version of a paper of the same title published in Seed Technology in 2012, volume 34, pages 203–215. Two additional years of data (2011 and 2012) concerning ergot and seed gall contaminants are included in this report.

Data were summarized to include the number of years in which each contaminant was found (frequency of occurrence) and the percentage of seed lots in which each contaminant was detected each year.

Results

Colonial bentgrass

For colonial bentgrass, 113 weed seed contaminants were detected, with 75 identified to species, 37 to genus, and 1 to family (Table 1). The most common contaminants, occurring in each of the 19 years evaluated, were *Alopecurus* spp. (foxtail), *Cerastium glomeratum* (sticky mouse-ear), *Daucus carota* L. subsp. carota (wild carrot), *Epilobium* spp. (willowherb), *Holcus* spp. (velvetgrass), *Juncus bufonius* L. (toad rush), *Poa annua* L. (annual bluegrass), and *Rorippa palustris* (L.) Besser (western yellowcress). Forty-one out of the 113 weed contaminants identified occurred in only a single year. The occurrence of any given species contaminant varied from year to year, and there was no indication of a trend toward increasing or decreasing frequency or level of occurrence for any species.

Ergot occurred in 41–87% of seed lots, and seed gall occurred in 3–29% of seed lots (Table 2). The level of ergot was relatively stable (41–57%) between 2002 and 2008, but in 2010, 2011, and 2012 increased to 77%, 75%, and 87% respectively. Percentage of lots with seed gall during 2002–2009 ranged between 2% and 10%, but levels in 2010, 2011, and 2012 increased to 15%, 21%, and 29%, respectively.

Creeping bentgrass

For creeping bentgrass, 61 weed seed contaminants were identified to species, 26 to genus, and 3 to family (Table 1). The most common contaminants, occurring in each of the 19 years evaluated, were *Capsella bursa-pastoris* (L.) Medik. (shepherd's-purse), *Epilobium* spp. (willowherb), and *Poa annua* (annual bluegrass). Twenty-eight of the 90 weed contaminants identified occurred in only one of the 19 years evaluated. Within any given year, 12 to 41 contaminant species or genera were identified.

Ergot occurred in 16-48% of seed lots, and seed gall was not detected in any of the samples examined (Table 2). Between 2002 and 2011, the percentage of lots with ergot ranged from 16% to 30%, but in 2012 the level increased to 48%.

Discussion

Results from this study indicated a large diversity of weed seed contaminants in bentgrass seed lots, although most contaminant species or genera occurred at a low level and in few years. This indicates that bentgrass seed growers are, for the most part, utilizing effective weed management practices for seed production. Weed contaminants that occurred annually indicate difficulty both in control within the field and in separating out the weed seeds during cleaning. In colonial bentgrass, these species were *Alopecurus* spp., *C. glomeratum*, *D. carota*, *Epilobium* spp., *Holcus* spp., *J. bufonius*, *P. annua*, and *R. palustris*. In creeping bentgrass, these species were *C. bursa-pastoris*, *Epilobium* spp., and *P. annua*. These species have seeds with physical properties, including size, shape and/or density, that make them difficult to separate from bentgrass seed during seed cleaning.

Of the 113 weed contaminants detected in colonial bentgrass and the 90 contaminants detected in creeping bentgrass, 69 were common to both grass species, 44 unique to colonial bentgrass, and 21 unique to creeping bentgrass (Table 1). The reason for the greater diversity of contaminants in colonial bentgrass, despite its lower acreage relative to creeping bentgrass, is unclear. Spatial and temporal distribution of weeds in grass seed cropping systems often is a consequence of cropping history and soil factors that may play a role in the diversity and frequency of weed seed contaminants found in bentgrass seed lots (Mueller-Warrant et al., 2008). Differences between colonial and creeping bentgrass were also noted in terms of pathogen contaminants, in particular the absence of seed galls and lower level of ergot in creeping bentgrass seed lots.

The sources or mechanisms of weed seed contamination in seed lot samples were not determined and are beyond the scope of this study. We hypothesize that the sources of most contaminants were weed populations growing in individual fields (i.e., the soil seed bank), but we cannot exclude the possibility of contaminant sources from outside the production fields, including wind-borne seed or introduction of contaminants during transport, storage, or conditioning of seed lots. Additional studies would be needed to determine the source of specific weed contaminants. Certainly the continual presence of species such as *Alopecurus* spp. and *Holcus* spp. reflect the inability of growers to selectively manage these perennial grass weed species with the currently labeled herbicides available for colonial bentgrass seed production. The annual presence of *P. annua* in seed lots may be the result of selection for diuron-resistant biotypes of this species and subsequent poor control of this species in the field over time.

In colonial bentgrass, ergot levels were relatively stable (41–57%) between 2002 and 2008, but a steady increase in contaminated lots from 41% in 2008 to 87% in 2012 is of concern. A large increase in ergot contamination also occurred in creeping bentgrass in 2012. The reason for this increase is not clear.

An increase in seed gall in colonial bentgrass beginning in 2009 was also noted, which is of even greater concern because *Anguina* species are of regulatory concern for export markets. In creeping bentgrass, however, seed gall was not detected. It is not clear why seed gall is occurring in colonial bentgrass but not creeping bentgrass.

Acknowledgments

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Table 1. Frequency of occurrence (years out of 19) and range (percentage of seed lots contaminated within a year) of weed seeds found in Oregon colonial bentgrass (*A. capillaris*) and creeping bentgrass (*A. stolonifera* L. var. *palustris*) seed lots. Data summarized for years 1986–1995 and 2002–2010.

		Colonial --- bentgrass ---		Creeping --- bentgrass ---	
Weed species	Common name	F[1]	Range[2]	F[1]	Range[2]
			(%)		(%)
Achillea millefolium L.	Common yarrow	1	0–1.6	—	—
Agrostis canina L.	Velvet bentgrass	—	—	1	0–2.2
Agrostis capillaris L.	Colonial bentgrass	—	—	7	0–8.9
Agrostis exarata Trin.	Spike bentgrass	15	0–8.4	8	0–3.4
Agrostis stolonifera L. var. *palustris* (Huds.) Farw.	Creeping bentgrass	1	0–1.6	—	—
Aira L. spp.	Hairgrass	8	0–4.8	3	0–1.1
Aira caryophyllea L.	Silver hairgrass	18	0–29.0	7	0–1.1
Alchemilla arvensis (L.) Scop.	Western ladysmantel	3	0–1.3	—	—
Allium vineale L.	Wild garlic	1	0–0.8	—	—
Alopecurus L. spp.	Foxtail	19	1.6–30.7	7	0–4.8
Alopecurus pratensis L.	Meadow foxtail	1	0–0.8	—	—
Amaranthus L. spp.	Pigweed	1	0–0.8	1	0–2.3
Amaranthus retroflexus L.	Redroot pigweed	3	0–1.1	—	—
Anthemis arvensis L.	Field chamomile	4	0–1.6	2	0–0.7
Amsinckia Lehm. spp.	Fiddleneck	—	—	1	0–0.4

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		Colonial --- bentgrass ---		Creeping| --- bentgrass ---	
Weed species	Common name	F[1]	Range[2]	F[1]	Range[2]
			(%)		(%)
Anthemis cotula L.	Dogfennel	11	0–6.6	3	0–1.4
Anthoxanthum L. spp.	Vernalgrass	14	0–11.0	6	0–2.2
Apera spica-venti (L.) P. Beauv.	Windgrass	6	0–3.3	10	0–13
Arabidopsis thaliana (L.) Heynh.	Mouse-ear cress	—	—	1	0–0.7
Barbarea vulgaris W. T. Aiton	Bitter wintercress	1	0–0.8	—	—
Brassicaceae	Brassicaceae	—	—	1	0–0.4
Brassica L. spp.	*Brassica* spp.	—	—	1	0–0.4
Briza minor L.	Little quackinggrass	2	0–1.6	—	—
Bromus tectorum L.	Downy brome	4	0–2.2	5	0–2.6
Capsella bursa-pastoris (L.) Medik.	Shepherd’s-purse	10	0–6.9	19	0.3–8.9
Cardamine L. spp.	Bitter cress	3	0–14.0	—	—
Carex L. spp.	Sedge	11	0–9.3	—	—
Cerastium fontanum Baumg. subsp. *vulgare* (Hartm.) Greuter & Burdet	Mouse-ear chickweed	12	0–3.7	5	0–1.4
Cerastium glomeratum Thuill.	Sticky mouse-ear	19	1.7–18.8	12	0–8.1
Chenopodium album L.	Common lamb’s-quarters	2	0–1.1	3	0–4.4
Cirsium arvense (L.) Scop.	Canada thistle	1	0–0.8	—	—
Crepis L. spp.	Hawksbeard	—	—	1	0–0.5
Crepis capillaris (L.) Wallr.	Smooth hawksbeard	1	0–3.2	2	0–0.7
Crepis setosa Haller f.	Hairy hawksbeard	3	0–1.3	6	0–0.9
Daucus carota L. subsp. *carota*	Wild carrot	19	1.6–53.0	18	0–6.5
Deschampsia cespitosa (L.) P. Beauv. subsp. *cespitosa*	Hairgrass, tufted	—	—	1	0–0.4
Descurainia sophia (L.) Webb ex Prantl	Flixweed	3	0–1.7	5	0–1.1
Digitaria Haller spp.	Crabgrass	1	0–0.8	1	0–0.9
Digitaria sanguinalis (L.) Scop.	Large crabgrass	3	0–1.9	3	0–1.5
Downingia Torr. sp.	Downingia	11	0–4.6	4	0–2.2
Eleocharis R. Br. spp.	Spikerush	9	0–6.5	—	—
Eleocharis obtuse (Willd.) Schult.	Blunt spikerush	9	0–7.3	1	1–0.4
Epilobium L. spp.	Willowherb	19	1.1–11.5	19	8.9–28.8
Eragrostis von Wolf spp.	Lovegrass	1	0–2.0	4	0–0.7
Erecaceae	Erecaceae	—	—	1	0–0.9
Erigeron L. spp.	Fleabane	1	0–1.0	—	—
Erysimum L. spp.	Treacle	—	—	1	0–0.5
Festuca L. sp.	Fescue	2	0–1.6	2	0–0.5
Fimbristylis Vahl spp.	Fimbristylis	6	0–4.8	—	—
Galium L. spp.	Bedstraw	5	0–2.3	4	0–0.7
Galium parisiense L.	Bedstraw, wall	17	0–22.0	6	0–1.0
Glyceria R. Br. spp.	Mannagrass	2	0–1.6	—	—
Gratiola neglecta Torr.	Hedge hyssop	2	0–1.3	—	—
Holcus L. spp.	Velvetgrass	19	16.5–44.0	9	0–2.2
Hypericum perforatum L.	Common St. John’s-wort	15	0–14.0	10	0–2.2
Hypochaeris radicata L.	Spotted cat’s-ear	4	0–1.6	2	0–0.4
Jacobaea vulgaris Gaertn.	Tansy ragwort	3	0–6.8	5	0–0.9
Holosteum umbellatum L.	Jagged chickweed	1	0–2.7	2	0–1.6

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Table 1. Frequency of occurrence (years out of 19) and range (percentage of seed lots contaminated within a year) of weed seeds found in Oregon colonial bentgrass (*A. capillaris*) and creeping bentgrass (*A. stolonifera* L. var. *palustris*) seed lots. Data summarized for years 1986–1995 and 2002–2010.

		Colonial --- bentgrass ---		Creeping --- bentgrass ---	
Weed species	Common name	F[1]	Range[2]	F[1]	Range[2]
			(%)		(%)
Juncus bufonius L.	Toad rush	19	1.9–30.2	14	0–4.3
Juncus L. spp.	Rush	3	0–11.3	—	—
Juncus tenuis Willd.	Path rush	9	0–7.3	—	—
Kickxia spuria (L.) Dumort.	Roundleaf toadflax	1	0–3.7	2	0–0.7
Lamium amplexicaule L.	Henbit	—	—	1	0–0.9
Lapsana communis L.	Nipplewort	1	0–0.9	—	—
Leontodon saxatillis Lam.	Rough hawkbit	1	0–0.8	2	0–0.5
Leucanthemum vulgare Lam.	Ox-eye daisy	4	0–2.4	1	0–0.3
Linaria maroccana Hook. f.	Spurred snapdragon	1	0–0.8	—	—
Lobelia L. spp.	Lobelia	1	0–2.4	—	—
Lolium L. spp.	Ryegrass	4	0–3.9	4	0–0.7
Lotus pedunculatus Cav.	Big trefoil	1	0–0.9	—	—
Lythrum hyssopifolia L.	Loosestrife, hyssop	12	0–27.4	8	0–1.1
Matricaria chamomilla L.	Sweet false chamomile	—	—	1	0–0.9
Matricaria discoidea DC.	Pineappleweed	9	0–3.3	18	0–11
Melissa officinalis L.	Balm	1	0–5.2	—	—
Mentha L. spp.	Mint	1	0–1.7	—	—
Mimulus L. spp.	Monkeyflower	7	0–10	—	—
Misopates orontium (L.) Raf.	Little snapdragon	1	0–0.8	—	
Myosotis L. spp.	Forget-me-not	1	0–1.7	—	—
Navarretia intertexta (Benth.) Hook.	Needleleaved navarretia	1	0–0.8	—	—
Navarretia squarrosa (Eschsch.) Hook. & Arn.	Skunkweed	3	0–1.6	2	0–0.7
Panicum capillare L.	Witchgrass	4	0–1.6	4	0–0.5
Papaver L. spp.	Poppy	—	—	1	0–0.5
*Parentucellia vicosa (*L.) Caruel	Parentucellia	6	0–3.4	2	0–1.1
Persicaria maculosa Gray	Ladysthumb	2	0–0.8	—	—
Phacelia Juss. spp.	Scorpionweed	7	0–2.6	1	0–0.4
Plantago lanceolata L.	Buckhorn plantain	2	0–4.1	—	—
Plantago major L.	Common plantain	14	0–5.3	16	0–8.9
Poa L. spp.	Bluegrass	9	0–21.9	9	0–2.2
Poa annua L.	Annual bluegrass	19	3.9–30.7	19	1.6–20.9
Poa compressa L.	Canada bluegrass	3	0–2.0	6	0–2.6
Poa nemoralis L.	Wood bluegrass	—	—	1	0–0.7
Poa palustris L.	Fowl bluegrass	2	0–2.7	7	0–5.4
Poa pratensis L.	Kentucky bluegrass	3	0–1.7	2	0–1.6
Poa trivialis L.	Rough bluegrass	9	0–32.5	8	0–3.3
Poaceae	Poaceae	6	0–4.4	1	0–0.9
Polygonum aviculare L.	Prostrate knotweed	1	0–1.1	—	—
Polygonum L. spp.	Smartweed, knotweed	1	0–0.9	1	0–0.5
Portulaca oleracea L.	Common purslane	—	—	1	0–2.2
Potentilla norvegica L.	Rough cinquefoil	—	—	1	0–0.5
Puccinellia lemmonii (Vasey) Scribn.	Lemmons alkaligrass	—	—	5	0–1.6
Puccinellia Parl. spp.	Alkaligrass	1	0–1.7	6	0–1.6
Rorippa curvisiliqua (Hook.) Besser ex Britton	Curvepod yellowcress	2	0–2.0	—	—
Populus L. spp.	Poplar	1	0–1.6	4	0–1.3

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		Colonial --- bentgrass ---		Creeping| --- bentgrass ---	
Weed species	Common name	F[1]	Range[2]	F[1]	Range[2]
			(%)		(%)
Rorippa palustris (L.) Besser	Western yellowcress	19	3.8–23.0	17	0–8.8
Rumex acetosella L.	Sheep sorrel	5	0–7.7	—	—
Rumex L. spp.	Dock	1	0–0.7	2	0–0.5
Sairocarpus pusillus (Brandegee) D.A. Sutton	Lesser snapdragon	2	0–1.7	5	0–0.9
Senecio vulgaris L.	Common groundsel	15	0–7.6	18	0–2.8
Sherardia arvensis L.	Field madder	1	0–1.4	—	—
Silene armeria L.	Sweet-William catchfly	1	0–0.8	—	—
Silene L. spp.	Catchfly	1	0–1.6	1	0–0.4
Sisymbrium altissimum L.	Tumble mustard	—	—	6	0–1.1
Sisymbrium officinale (L.) Scop.	Hedge mustard	2	0–1.0	1	0–0.4
Solanum L. spp.	Nightshade	1	0–1.9	—	—
Solanum villosum Mill.	Hairy nightshade	—	—	1	0–0.4
Sonchus asper (L.) Hill	Spiny sowthistle	4	0–2.4	3	0–0.8
Sonchus oleraceus L.	Annual sowthistle	1	0–1.6	—	—
Spergula arvensis L.	Corn spurry	—	—	1	0–0.3
Spergularia rubra (L.) J. Presl & C. Presl	Red sandspurry	14	0–4.6	3	0–1.8
Sporobolus R. Br. spp.	Dropseed	1	0–5.2	4	0–0.7
Stellaria media (L.) Vill.	Common chickweed	4	0–2.0	1	0–0.9
Thlaspi arvense L.	Field pennycress	1	0–0.8	—	—
Trifolium aureum Pollich	Hop clover	2	0–0.8	—	—
Trifolium L. spp.	Clover	1	0–1.0	—	—
Trifolium pratense L.	Red clover	1	0–0.8	—	—
Trifolium repens L.	White clover	1	0–1.0	1	0–0.3
Triodanis perfoliata (L.) Nieuwl.	Venus lookingglass	2	0–1.5	—	—
Vaccinium L. spp.	Blueberry	1	0–3.9	2	0–2.2
Ventenata dubia (Leers) Coss.	Ventenata	7	0–26	—	—
Verbascum thapsus L.	Common mullein	1	0–1.9	6	0–1.8
Veronica L. spp.	Speedwell	15	0–13.3	16	0–6.5
Veronica peregrina L.	Purslane speedwell	—	—	3	0–0.9
Viola cornuta L.	Viola	1	0–0.9	—	—
Vulpia myuros (L.) C. C. Gmel.	Rattail fescue	16	0–11.0	10	0–4.8

[1] F = Frequency of occurrence (years out of 19)

[2] Range = Percentage of seed lots contaminated within a year

Table 2. Percentage of seed lots of colonial bentgrass or creeping bentgrass with ergot (*Claviceps purpurea*) or seed gall nematode galls (*Anguina agrostis*) in 2002–2012.[1]

	---------------- Colonial bentgrass ----------------		-------------- Creeping bentgrass --------------	
Year	Ergot	Seed gall	Ergot	Seed gall
	(%)			
2002	53.3	3.3	16.8	0
2003	44.2	7.8	23.9	0
2004	42.5	1.6	19.7	0
2005	42.3	7.7	22.2	0
2006	57.0	9.7	20.1	0
2007	54.5	6.9	18.6	0
2008	40.7	1.9	30.0	0
2009	66.7	10.0	25.7	0
2010	77.4	14.5	16.2	0
2011	75.0	20.6	28.3	0
2012	87.3	29.1	47.9	0

[1] Percentage of total seed lots within each year.

ENVIRONMENTAL FACTORS INFLUENCING AIRBORNE ERGOT ASCOSPORE CONCENTRATIONS IN PERENNIAL RYEGRASS SEED FIELDS IN THE COLUMBIA BASIN OF OREGON

J.K.S. Dung, S.C. Alderman, D.L. Walenta, and P.B. Hamm

Introduction

Ergot is an important disease of perennial ryegrass and can be a persistent problem in seed production systems. The disease is caused by the fungal pathogen *Claviceps purpurea*, which has a very wide host range among grasses and grains in North America. The fungus infects flowers prior to fertilization and colonizes the ovaries, resulting in the production of sclerotia rather than viable seed. Sclerotia are the overwintering structures of the fungus and produce airborne ascospores that serve as primary inoculum the following growing season. Ergot infection and infestation cause economic losses at various stages of grass seed production, including direct yield loss due to the production of sclerotia instead of seed, costs associated with protective fungicide applications, seed loss during recleaning processes that are required to remove ergot sclerotia from infested seed lots, and rejection of certification.

Cool-season grasses are grown for seed in a wide range of climates in Oregon, including mild and moist conditions in the Willamette Valley, semi-arid high elevation deserts in central Oregon and the Columbia Basin, and high mountain valleys in northeastern Oregon. Although ergot is a continual problem for grass seed production in eastern Oregon, the incidence and severity of ergot epidemics in grass grown for seed can vary among and within growing regions and from year to year (Alderman, 1991; Alderman et al., 1996; Alderman et al., 1998). In some years, the timing of ascospore release by the fungus may not coincide with grass anthesis, which is the only period of host susceptibility (Walenta et al., 2010).

Previous studies have investigated the timing and aerobiology of ergot ascospore production in Oregon, especially in Kentucky bluegrass (Alderman, 1993; Walenta et al., 2010). In the Willamette Valley, ascospore release in the field was associated with rain events occurring 2 to 3 days prior and was not correlated with temperature or relative humidity (Alderman, 1993). In the semi-arid Columbia Basin of eastern Oregon, grass seed production fields are frequently irrigated, and air or soil temperatures may play more important roles in ascospore release than precipitation events. A further understanding of the environmental conditions that contribute to ergot ascospore production in eastern Oregon grass seed production systems is needed and could provide information that can be used to predict ascospore release and improve the timing of fungicide applications.

The objectives of this study were to: (1) determine the seasonal timing and concentration of ergot ascospores in fields of perennial ryegrass grown for seed in the Columbia Basin of eastern Oregon; (2) identify environmental factors that contribute to ascospore production; and (3) develop a model that can be used to predict ascospore production events in perennial ryegrass fields located in the Columbia Basin.

Materials and Methods

Spore sampling

Two commercial perennial ryegrass seed fields in Umatilla County, OR were included in this study. Field #1 was planted with cultivar 'Pavilion', and field #2 was planted with cultivar 'Top Hat II'. Both fields were 125 acres in size and were planted in the fall of 2011. Field #1 was located at an elevation of approximately 890 feet elevation, and field #2 was located at 712 feet. The fields were subjected to similar cultural practices and irrigated on a regular basis during the growing season using center pivot irrigation.

Burkard 7-day recording volumetric spore samplers were used to collect airborne ascospores of *C. purpurea*. In 2012, a spore sampler was placed in field #1 from May 11 to July 8. In 2013, spore samplers were placed in field #1 from April 3 to June 19 and in field #2 from April 3 to June 15. Spore samplers were placed approximately 500 feet from the field border with the air intake orifice located just above the mature canopy height. Spore trap tapes were collected and replaced weekly and were processed and analyzed as described by Alderman (1993).

Environmental data collection

Weather data were compiled from the HRMO weather station in the AgriMet Northwest Cooperative Agricultural Weather Network located at the Hermiston Agricultural Research and Extension Center. Soil temperatures were recorded 2 inches below the soil surface. Daily and cumulative degree days were calculated for both air and soil temperatures using a base temperature of 50°F and an upper threshold temperature of 77° F for degree day calculations. These values were based on previous incubation studies, which found that ergot sclerotia germination was inhibited by temperatures outside of this range (Mitchell and Cooke, 1968).

Statistical analyses

Data collected from both fields and seasons were combined for statistical analyses. Correlation analysis was performed to identify significant ($P < 0.05$) correlations between daily ascospore concentrations and environmental data collected from the HRMO weather station. Local regression, which does not assume a linear relationship, was used to identify trends in daily ascospore counts against environmental variables (Cleveland et al., 1988). Results from correlation and local regression analyses were used to visually identify upper and lower threshold values of environmental factors that were significantly associated with ascospore occurrence. An environmental favorability index (EFI) model that included maximum and minimum soil temperatures, daily soil degree days, and mean dew point was developed to predict spore occurrence. Point values were assigned based on the following environmental variable ranges: maximum daily soil temperature between 59 and 72°F = 1 point; minimum daily soil temperature between 57 and 70°F = 1 point; daily soil degree days between 11 and 20 = 1 point; and mean daily dew point between 37 and 50°F = 1 point. Zero points were accumulated for any variable with values outside the above ranges. Chi-square analysis was used to determine the predictive ability of each environmental variable and the EFI model.

Results and Discussion

Spore traps used to monitor daily ascospore concentrations captured 27 spores in field #1 on the first day of trapping in 2012 (May 11), so spore traps were placed in fields earlier (April 3) in the 2013 season. The first occurrence of spores in 2013 was on April 24 in field #1 and on April 30 in field #2, when accumulated air temperature degree days reached 198 and 255, respectively. Accumulated soil temperature degree days at first spore occurrence in 2013 were 68 and 100 for field #1 and field #2, respectively. The majority of spores were captured between May 1 and June 15, with fewer spores sporadically captured before and after this time period In field #1, more than nine times as many spores were captured in 2013 (more than 56,000) than in 2012 (more than 6,000. More than 114,000 ergot ascospores were captured in field #2 during the 2013 season. Such high concentrations of spores represent significant sources of primary inoculum that can be extremely difficult to control.

Significant correlations ($P < 0.05$) were observed between spore counts and the following environmental variables collected from the HRMO weather station: minimum ($r = 0.25$), maximum ($r = 0.26$), and mean ($r = 0.29$) air temperatures; minimum ($r = 0.45$), maximum ($r = 0.24$), and mean ($r = 0.33$) soil temperatures; daily air ($r = 0.24$) and soil ($r = 0.38$) degree days; mean dew point ($r = 0.30$); and evapotranspiration ($r = 0.18$). Precipitation was not a significant factor in this study ($P > 0.67$), likely due to the regular irrigation that is required to grow grass seed crops in the semi-arid Columbia Basin.

Local regression identified several trends that were used to identify upper and lower threshold values for environmental factors significantly correlated with spore production. Peak spore production was associated with minimum air temperatures between 41 and 54°F and with minimum, maximum, and mean soil temperatures between 57 and 72°. These results are consistent with previous studies concluding that the highest percentage of ergot sclerotia germination was observed at incubation temperatures between 50 and 77°F, with germination reduced at temperatures below 41°F and above 77°F (Mitchell and Cooke, 1968). Daily soil degree days between 11 and 20 and a mean dew point between 37 and 50°F were also associated with spore production. Overall, variables associated with soil temperature (minimum, maximum, mean, and daily degree days) appeared to be more associated with spore production than other variables.

The environmental factors used to predict ergot ascospore occurrence in this study included minimum daily air temperature between 41 and 54°F, maximum daily soil temperature between 59 and 72°F, minimum and mean daily soil temperatures between 57 and 70°F, daily soil degree days between 11 and 20, and mean daily dew point between 37 and 50°F. When used to predict the appearance of at least one spore, all environmental variables except minimum air temperature were significant predictors ($P < 0.05$), with variables ranging in accuracy from 60 to 83 (Table 1). Table 1 also shows that all environmental variables were significant when used to predict the occurrence of at least 10 spores per day (64 to 90% accuracy) or at least 100 spores per day (60 to 89% accuracy). Environmental variables based on soil temperatures provided the most accurate predictions of spore events. A cumulative EFI was developed that included maximum soil temperature, minimum soil temperature, daily soil degree days, and mean dew point thresholds.

A cumulative EFI value of 2 correctly predicted the occurrence of at least one spore with an accuracy of 82% and correctly predicted the occurrence of at least ten spores with an accuracy of 86% (Table 2). A cumulative EFI value of 3 predicted the occurrence of at least 100 spores with an accuracy of 91% (Table 2). These results suggest that predictive models can be a useful tool to predict ergot ascospore production in the Columbia Basin.

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Table 1. Predictive accuracy of environmental variables used to forecast the occurrence of at least 1, 10, or 100 *Claviceps purpurea* ascospores.

	Spores present/absent			≥10 spores present/absent			≥100 spores present/absent		
Environmental variable	Correct prediction	False positive	False negative	Correct prediction	False positive	False negative	Correct prediction	False positive	False negative
	(%)								
Minimum air T = 41 to 54°F	60.3[1]	16.9	22.8	64.0	21.2	14.8	60.3	29.1	10.6
Maximum soil T = 59 to 72°F	74.1	0.0	25.9	86.2	0.0	13.8	88.9	4.8	6.3
Minimum soil T = 57 to 70°F	82.5	3.7	13.8	84.1	9.0	6.9	81.5	16.4	2.1
Mean soil T = 57 to 70°F	77.8	0.5	21.7	90.0	0.5	9.5	88.4	7.4	4.2
Daily soil degree days = 11 to 20	74.6	0.0	25.4	86.8	0.0	13.2	89.4	4.8	5.8
Mean dew point = 37 to 50°F	67.7	15.4	16.9	69.3	20.6	10.1	66.7	28.0	5.3

[1] Chi-square result was not significant at $P < 0.05$. All other chi-square values (not shown) were significant at $P < 0.05$.

Table 2. Predictive accuracy of an environmental favorability index (EFI) model used to forecast the occurrence of at least 1, 10, or 100 *Claviceps purpurea* ascospores.[1]

	Spores present/absent			≥10 spores present/absent			≥100 spores present/absent		
Environmental Favorability Index (EFI)	Correct prediction	False positive	False negative	Correct prediction	False positive	False negative	Correct prediction	False positive	False negative
	(%)								
EFI ≥ 1	78.9	15.3	5.8	77.3	22.2	0.5	66.1	33.9	0.0
EFI ≥ 2	81.5	3.7	14.8	86.2	7.4	6.4	83.6	14.8	1.6
EFI ≥ 3	73.5	0.0	26.5	85.7	0.0	14.3	90.5	3.7	5.8
EFI ≥ 4	65.1	0.0	34.9	77.2	0.0	22.8	86.2	1.6	12.2

[1] All chi-square values (not shown) were significant at $P < 0.0001$.

EFFECTS OF NITROGEN FERTILIZER ON SEED YIELD AND YIELD COMPONENTS IN YELLOW MUSTARD

A.S. DuVal, T.G. Chastain, and C.J. Garbacik

Introduction

Yellow mustard (*Sinapis alba* L.) is a new multipurpose rotation oilseed crop for Willamette Valley agriculturalists, especially non-irrigated operations. Yellow mustard can also be used to produce condiment mustard, as a green manure crop, and as a biopesticide. Although yellow mustard seed production is relatively new to the Willamette Valley, Oregon's north-central counties have been producing mustard seed for more than a decade.

The primary source of contention over large-scale *Brassica* oilseed production in the Willamette Valley is the risk of cross-pollination with high-value vegetable seed crops. However, yellow mustard is a distant relative of the *Brassica* species and is not a compatible cross with any specialty seed crops (Lelivelt et al., 1993; Hawkins et al., 1996; Vaughn, 1997; Brown et al., 2005; Quinn, 2010). Therefore, *S. alba* is not included in the current Oregon legislative regulation of canola (*B. napus*) production.

The objectives of this study were to (1) determine the relationship of nitrogen (N) fertilizer to seed yield and yield components of yellow mustard, and (2) examine how N fertilizer affects plant structure, lodging, and leaf area.

Methods

This field experiment utilized the 'IdaGold' yellow mustard cultivar. It was planted on March 11, 2013 at the Hyslop Crop Science Research Farm near Corvallis, OR, in a randomized complete block design with four replications. A single preplant herbicide (Teflon®) application was employed to control germinating weed seeds; no pesticide applications were made during the growing season. On April 4, an Orbit-air spreader was utilized to apply urea fertilizer at four treatment rates (50, 100, 150, and 200 lb N/acre). Control plots were not treated.

Plant growth, development, and lodging rates were tracked weekly throughout the growing season. Two adjacent one-square-foot quadrats were sampled from each plot on April 30, when the majority of the plants had reached the rosette stage, but prior to stem elongation. Ten plants were randomly selected from each sample for height and leaf area measurements. One-sided leaf area measurements were obtained with the LI-3100 leaf area meter. This procedure was repeated on May 20, when 90% of the plants had bolted and attained early inflorescence emergence.

Two weeks prior to harvest, two one-square-foot subsamples were collected from each plot. Above - ground biomass and seed yield components were recorded for these subsamples. Wet weight, dry weight, and the total number of plants per quadrat were determined. Plant height and further component analyses (branches per plant, pods per branch, and seeds per pod) were conducted utilizing ten random, representative plants per subsample.

From each plot, the center sections (6 feet x 50 feet) were swathed on July 16 and combined on July 23. Harvest index, clean-out, total seed yield, and thousand-seed weights were determined.

The following measurements will be conducted in 2014 and the data presented in the *2014 Seed Production Research Report*: carbon:nitrogen ratio of biomass sampled at the rosette and inflorescence emergence stages, seed protein, and seed oil content for each treatment.

Results and Discussion

Vegetative measurements

Nitrogen fertilizer treatments influenced yellow mustard characteristics at varying degrees of significance. Due to warm weather during the 2013 growing season, mustard plants grew at a greater rate than anticipated or previously observed. Lodging was present only with the two highest N rates—150 and 200 lb N/acre. However, even at these rates, the typical negative effects of lodging (reduced pollination, increased harvest difficulty, and reduced yield) were not observed.

At the rosette stage, treatments receiving N were taller than the control (Figure 1). Measurements conducted at inflorescence emergence allow for greater differentiation in height among treatments, with the greatest height observed in 150 and 200 lb N/acre plots. When measured at harvest, the average plant height was only about 7% greater than at inflorescence emergence, indicating that yellow mustard reaches nearly full mature height by inflorescence emergence. Plant height at harvest was influenced incrementally by the amount of N applied, with the greatest height attained at the highest N rate.

Above-ground biomass measurements illustrated that plots not receiving N fertilizer (control plots) consistently produced significantly less vigorous stands at the rosette and inflorescence emergence stages (Figure 2). At the rosette stage, the 100 lb N/acre treatment generated more biomass than did the 50 and 150 lb N/acre treatments. However, measurements at inflorescence emergence showed that the 150 lb N/acre rate yielded significantly more biomass than both the 50 and 100 lb N/acre rates. At the rosette stage, the 200 lb N/acre treatment was similar in biomass to the 50, 100, and 150 lb N/acre rates. At inflorescence emergence, the 200 lb N/acre treatment was similar to the 150 lb N/acre rate.

Due to midseason precipitation, control plots accumulated sufficient biomass by harvest and subsequently were not statistically different from plots receiving 50 or 100 lb N/acre. Interestingly, above-ground biomass at harvest with the 200 lb N/acre rate differed only from that in the control plots and plots receiving 50 lb N/acre.

As expected, N fertilizers notably influenced yellow mustard leaf area, a measurement of plant photosynthetic capacity (Figure 3). Typically, increasing N fertilizer rates resulted in an increase in average leaf area of 5.4% to 37.9% between rosette stage and inflorescence emergence, with only the 100 lb N/acre treatment experiencing a 2% decrease in leaf area. The control treatment experienced a 70% increase in leaf area from rosette to inflorescence emergence.

At both rosette and inflorescence emergence, control plots maintained significantly lower leaf area, and they were the last to reach canopy closure. At the rosette stage, there were no differences in leaf area between the 50 and 100 lb N/acre rates, nor among the 100, 150, and 200 lb N/acre rates. However, at inflorescence emergence, leaf area was greatest with 150 and 200 lb N/acre rates.

Yield components

Yellow mustard seed yield components are categorized into number of branches (main stem, primary, and secondary), total number of pods per branch type, and total quantity of seeds per branch type. N had a substantial influence on all yield components, beginning with branching structure (Table 1). Plots receiving 200 lb N/acre had significantly greater total branch count compared to both the control plots and the plots

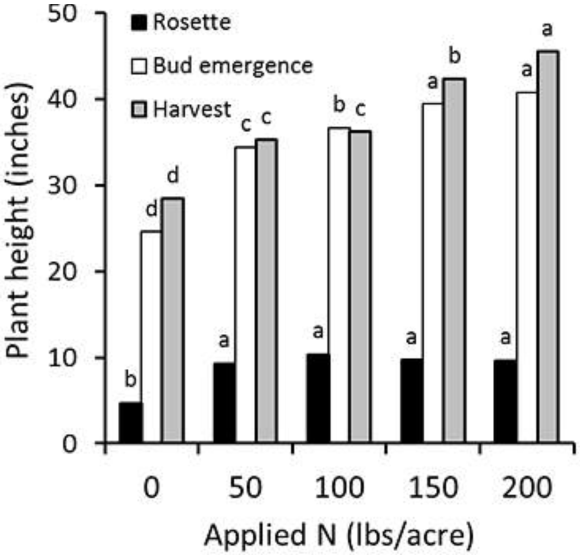

Figure 1. Effect of N fertilizer on yellow mustard plant height at rosette, inflorescence, and harvest. Means within growth stages or harvest are not statistically significant ($P = 0.05$) if followed by the same letter.

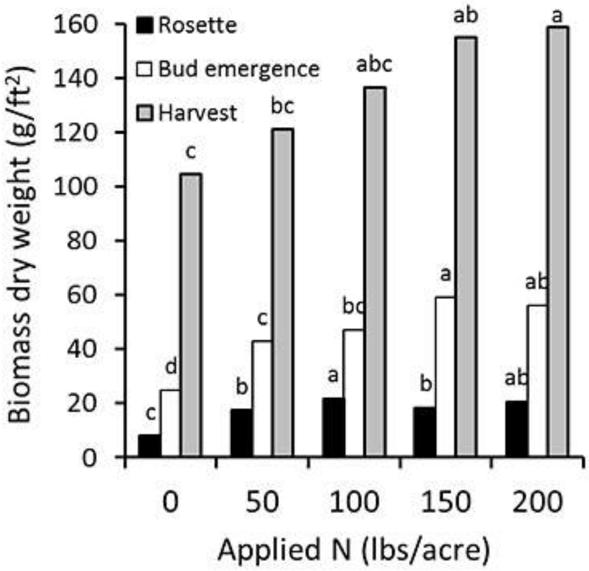

Figure 2. Effect of N fertilizer on yellow mustard above-ground biomass at rosette, inflorescence emergence, and harvest. Means within growth stages or harvest are not statistically significant ($P = 0.05$) if followed by the same letter.

receiving 50 lb N/acre. With a greater number of branches at the higher N rates, plants receiving 150 and 200 lb N/acre surpassed the control treatment in the number of main stem and primary pods produced (Table 1), as well as the number of seeds produced per main stem and primary pod (Table 2). Applications of 200 lb N/acre significantly increased the number of secondary branches per plant above that seen with the control, 50, and 100 lb N/acre treatments. However, N fertilizer did not generate significant differences in secondary pod production nor in the quantity of secondary seeds produced per pod.

A similar trend was observed when comparing average main seed mass across N fertilizer rates (Table 2). The control plots produced the lowest seed mass on main stems (although the control, 50 lb N/acre, and 100 lb N/acre treatments were not significantly different). Seeds produced on main stems with the 150 and 200 lb N/acre rates attained the greatest mass; the 200 lb N/acre rate far surpassed other rates in terms of primary seed mass—32% greater than the 150 lb N/acre treatment and 177% greater than the control.

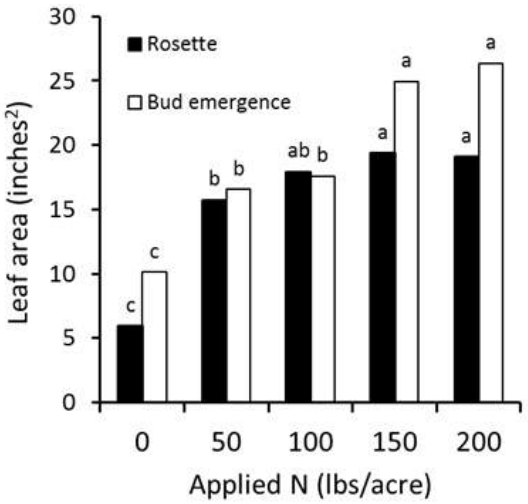

Figure 1. Effect of N fertilizer on yellow mustard leaf area at the rosette and inflorescence emergence growth stages. Means within growth stages are not statistically significant (*P* = 0.05) if followed by the same letter.

Table 1. Effect of applied N on the number of plant branches and pods produced by yellow mustard.[1]

Applied nitrogen	Branches[2]			Pods[3]			
	Total	1°	2°	Total	Main	1°	2°
(lb N/acre)	(number/plant)			(number/plant)			
0	3.2 b	2.0 b	0.2 b	56.9 c	36.3 c	20.3 c	0.4 ab
50	3.3 b	2.2 b	0.1 b	58.3 c	38.7 c	19.5 c	0.1 b
100	3.6 ab	2.4 ab	0.2 b	67.9 bc	40.7 bc	26.0 bc	1.2 ab
150	3.8 ab	2.5 ab	0.3 ab	78.4 ab	45.3 ab	32.2 ab	0.8 ab
200	4.3 a	2.8 a	0.5 a	87.8 a	47.7 a	38.6 a	1.5 a

[1] Means within each column are not statistically significant by Fisher's LSD (*P* = 0.05) if followed by the same letter.
[2] Total = total number of branches; 1° = primary branches; 2° = secondary branches
[3] Total = total number of pods; main = main stem; 1° = primary branches; 2° = secondary branches

Table 2. Effect of applied N on seed number and seed mass harvested from main stems, primary branches, and secondary branches in yellow mustard.[1]

Applied nitrogen	Seed number[2]				Seed mass[2]	
	Total	Main	1°	2°	Main	1°
(lb N/acre)	(number/plant)				(g/plant)	
0	205.3 d	135.0 d	68.7 c	1.6 a	0.84 d	0.43 d
50	248.2 cd	169.7 c	78.1 c	4.4 a	1.14 c	0.52 cd
100	295.1 bc	183.1 bc	107.5 bc	4.4 a	1.22 bc	0.71 bc
150	336.8 ab	202.5 ab	131.1 ab	3.1 a	1.41 ab	0.90 b
200	400.4 a	222.1 a	172.6 a	6.7 a	1.58 a	1.19 a

[1] Means within each column are not statistically significant by Fisher's LSD (*P* = 0.05) if followed by the same letter.
[2] Total = total number of seeds; main = main stem; 1° = primary branches; 2° = secondary branches

Seed yield

Considering the strong influence of N on yield components, it is no surprise that N fertilizers also had a complex but significant influence on seed yield in terms of seed number and seed weight (Table 3). The 200 lb N/acre rate produced the highest seed yield of 2,295 lb/acre, resulting primarily from the overall quantity of seeds produced. The control yielded 1,363 lb/acre. In 2013, the general relationship between applied N fertilizer and yellow mustard seed yield was that yield increased with increasing N.

This study addresses N fertilizer application rates as well as yellow mustard growth and developmental patterns for optimum seed yield under Willamette Valley environmental conditions and illustrates the potential of this crop to emerge as a successful multimarket, low-input, rotation crop option.

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Table 3. Effect of applied N on seed weight and seed yield in yellow mustard.[1]

Applied nitrogen	Seed weight[2]	Seed yield
(lb N/a)	(mg)	(lb/a)
0	6.923 bc	1,363 d
50	6.825 c	1,555 c
100	6.835 bc	1,575 bc
150	7.042 ab	1,725 b
200	7.192 a	2,295 a

[1] Means presented within each column are not statistically significant by Fisher's LSD (*P*= 0.05) if followed by the same letter.

[2] Seed weight (mg) was calculated from thousand-seed-weight measurements.

EFFECTS OF PLANTING DATE, FLAX VARIETY, AND CHEMICAL WEED MANAGEMENT TREATMENTS ON FLAX BIOMASS AND SEED YIELD

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

Introduction

Flax (*Linum usitatissimum*) has been grown for seed in Oregon since approximately 1849. During the following decades, it was widely used as a first crop on newly cultivated land, but by 1939 production had become more limited (Hill, 1939). However, leading up to and throughout World War II, there was significant production of fiber flax in Oregon. Decreased fiber prices, combined with the labor-intensive process of harvesting fiber flax, led to the decline of Oregon fiber flax production during the 1950s. The last flax processing plant closed in the 1960s. Some limited production of flax grown for seed continues today.

Western Oregon cropping systems are dominated by grass grown for seed and small grains. Efforts to diversify with alternative broadleaf crops are ongoing. There has been renewed interest on the part of private industry in producing flax for both seed and fiber. One of the challenges with producing flax is re-evaluating best management agronomic practices for improved flax varieties. Weed management and other unknown factors (planting date, soil fertility management, harvest methods, etc.) are often cited as concerns by growers. Trials were conducted to assess weed control options in flax under western Oregon production conditions in response to this renewal of interest in flax grown for fiber and a continued modest interest in flax seed production.

Materials and Methods

Eight trials were conducted at the Oregon State University Hyslop Research Farm to assess crop safety and weed control efficacy of herbicides labeled for use in flax or herbicides we believed to have potential for use in flax. The experimental design of all studies was a randomized complete block with four replications. Two flax varieties were used in these studies. The variety 'Agatha' was bred for suitability as a fiber crop, and 'Linore' is a standard variety grown for seed in the Pacific Northwest. 'Agatha' and 'Linore' were planted in the fall and spring of the 2012 growing season and again in the fall and spring of the 2013 growing season. The 2012 trials were planted with a Nordsten seed drill, and the 2013 trials were planted with a flax planter that scatters seed in a row approximately 4 inches wide. All herbicide treatments were applied with a bicycle-wheeled sprayer calibrated to deliver 20 gpa. In the fall-planted trials, trifluralin was applied before planting. In 2012, trifluralin was incorporated by the planting equipment and hand raking. In 2013, it was incorporated by the planting equipment alone. Weed control efficacy and flax injury were evaluated visually. Flax biomass data was obtained by harvesting and drying 10.8 square feet of above-ground biomass. Flax seed was direct combined with a small plot combine. Data were analyzed using ANOVA and means separated by LSD.

Results

Fall planting of both varieties resulted in greater biomass and seed yield than did spring planting, indicating that flax is ideally suited to the wet, relatively warm winters of western Oregon (Tables 1–8). Both varieties responded similarly to herbicide treatments, regardless of planting date (Tables 1–8). Post-emergent applications of bromoxynil-MCPA delayed flax flowering and maturity by approximately one week (data not shown). None of the herbicides tested caused lasting significant flax injury except fluroxypyr-bromoxynil, which is labeled for use in small grains to control volunteer flax up to 4 inches tall (application rate of 0.48 lb ai/acre). Fluroxypyr-bromoxynil applied to less dense stands of volunteer flax at this higher rate and with a more appropriate timing (newly emerged volunteer flax) likely would provide good to excellent control of volunteer flax in grass and small grain crops. Trifluralin applications also caused injury to flax (reduced emergence), but this injury was no longer visible by flax harvest and resulted in only modest decreases in flax biomass and seed yield.

The presence of weeds in several of the studies allowed us to rate weed control efficacy of the herbicide treatments on various important weed species. For example, mesotrione applied post-emergent in 2012 controlled 93% of volunteer meadowfoam (Table 1). In spring-planted flax, pyrasulfotole-bromoxynil controlled 85 to 90% of sharp-point fluvellin in 2012 (Tables 3 and 4). Post-emergent applications of mesotrione controlled sharp-point fluevellin 60 to 74% in both years (Tables 3, 4, and 8). S-metolachlor applied pre-emergent one day following flax planting in 2012 controlled 100% of annual bluegrass and lady's mantle, 93 to 98% of ivy-leaved speedwell, and 85 to 87% of lesser seeded bittercress (Tables 5 and 6). In the same study, trifluralin applied pre-emergent controlled 93 to 95% of annual bluegrass, while post-emergent-applied mesotrione controlled 89 to 90% of lesser seeded bittercress (Tables 5 and 6).

This agronomic and weed management information should be evaluated by growers and industry to determine whether flax production has a role to play in crop diversification strategies in western Oregon. For a list of herbicide products currently labeled for use in flax production, refer to the flax chapter in the *Pacific Northwest Weed Management Handbook*, which is updated annually. Further studies are needed, including those designed to "rediscover" agronomic requirements for improved varieties of flax. Among these would be more refined studies on determination of optimum flax planting dates and seeding rates as well as those designed to determine optimum flax fertility requirements.

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Table 1. Weed control, crop injury, dry biomass, and seed yield of 'Agatha' flax planted November 2, 2011.[1]

			Meadowfoam	------------------------ Flax ------------------------		
			5/25/2012	5/25/2012	7/27/2012	8/23/2012
	Rate	Date applied	Control	Injury	Dry biomass	Seed yield
	(lb ai/a)		------------- (%)	------------	(lb/a)	(bu/a)
Check	—	—	0 c	0 d	6,806 a	17.6 b
Trifluralin[2]	0.75	11/2/11	30 bc	0 d	7,358 a	21.2 ab
s-metolachlor	1.43	11/2/11	20 bc	9 bc	7,021 a	19.5 ab
Pendimethalin	1.42	11/2/11	45 abc	0 d	8,370 a	23.0 a
Mesotrione	0.094	11/2/11	50 abc	0 d	8,155 a	20.2 ab
Mesotrione	0.094	4/24/12	93 a	9 bc	6,377 a	19.2 ab
Fluroxypyr-bromoxynil	0.32	4/24/12	70 ab	75 a	3,127 b	7.0 c
Bromoxynil-MCPA	0.35	4/24/12	65 ab	13 b	6,500 a	18.4 b
Clopyralid	0.25	4/24/12	0 c	5 cd	8,247 a	18.2 b

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

[2] Preplant incorporated.

Table 2. Crop injury, dry biomass, and seed yield of ‘Linore’ flax planted November 2, 2011.[1]

			------------------------ Flax ------------------------		
			5/25/2012	7/19/2012	7/19/2012
	Rate	Date applied	Injury	Dry biomass	Seed yield
	(lb ai/a)		(%)	(lb/a)	(bu/a)
Check	—	—	0 b	6,224 a	30.7 b
Trifluralin[2]	0.75	11/2/11	3 b	5,978 a	30.1 b
s-metolachlor	1.43	11/2/11	0 b	6,960 a	34.2 ab
Pendimethalin	1.42	11/2/11	0 b	7,419 a	36.5 a
Mesotrione	0.094	11/2/11	1 b	6,592 a	36.5 a
Mesotrione	0.094	4/24/12	6 b	5,978 a	29.2 b
Fluroxypyr-bromoxynil	0.32	4/24/12	41 a	5,519 a	20.6 c
Bromoxynil-MCPA	0.35	4/24/12	1 b	6,561 a	32.2 ab
Clopyralid	0.25	4/24/12	0 b	6,592 a	33.1 ab

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

[2] Preplant incorporated.

Table 3. Weed control, crop injury, dry biomass, and seed yield of ‘Agatha’ flax planted April 18, 2012.[1]

			Sharp-point fluvellin	--------------------- Flax ---------------------		
			7/9/2012	7/9/2012	8/13/2012	8/13/2012
	Rate	Date applied	Control	Injury	Dry biomass	Seed yield
	(lb ai/a)		------------- (%) ------------		(lb/a)	(bu/a)
Control	—	—	0 d	0 b	1,977 a	9.9 ab
s-metolachlor	1.43	4/18/12	25 cd	3 b	1,740 a	7.8 bc
Pendimethalin	1.42	4/18/12	48 bc	0 b	2,046 a	11.3 a
Mesotrione	0.094	4/18/12	43 bc	0 b	2,255 a	10.2 ab
Mesotrione	0.094	6/13/12	68 ab	0 b	1,986 a	10.2 ab
Fluroxypyr-bromoxynil	0.32	6/13/12	0 d	79 a	359 b	0.4 d
Bromoxynil-MCPA	0.35	6/13/12	0 d	0 b	1,765 a	7.2 bc
Clopyralid	0.25	6/13/12	13 d	0 b	2,137 a	6.0 c
Pyrasulfotole-bromoxynil	0.241	6/13/12	85 a	3 b	1,796 a	7.3 bc

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

Table 4. Weed control, crop injury, dry biomass, and seed yield of ‘Linore’ flax planted April 18, 2012.[1]

			Sharp-point fluvellin	Flax		
			7/9/2012	7/9/2012	8/13/2012	8/13/2012
	Rate	Date applied	Control	Injury	Dry biomass	Seed yield
	(lb ai/a)		(%)	(%)	(lb/a)	(bu/a)
Control	—	—	0 d	0 c	1,298 a	12.7 bc
s-metolachlor	1.43	4/18/12	0 d	0 c	1,825 a	14.8 abc
Pendimethalin	1.42	4/18/12	30 c	0 c	2,030 a	17.8 a
Mesotrione	0.094	4/18/12	23 cd	0 c	1,972 a	18.5 a
Mesotrione	0.094	6/13/12	60 b	0 c	1,837 a	16.0 ab
Fluroxypyr-bromoxynil	0.32	6/13/12	0 d	60 a	561 b	1.9 d
Bromoxynil-MCPA	0.35	6/13/12	0 d	0 c	1,774 a	13.7 bc
Clopyralid	0.25	6/13/12	8 d	0 c	2,003 a	10.9 c
Pyrasulfotole-bromoxynil	0.241	6/13/12	90 a	10 b	1,273 a	12.0 bc

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

Table 5. Weed control, crop injury, dry biomass, and seed yield of ‘Agatha’ flax planted November 11, 2012.[1]

			Annual bluegrass	Lady's mantle	Lesser-seeded bittercress	Ivy-leaved speedwell	Flax		
			2/18/2013	2/18/2013	3/19/2013	3/19/2013	Injury	Dry biomass	Seed yield
	Rate	Date applied	Control				3/19/2013	8/14/2013	8/27/2013
	(lb ai/a)		(%)				(%)	(lb/a)	(bu/a)
Check	—	—	0 b	0 c	0 c	0 c	0 c	12,161 a	18.0 a
Trifluralin[2]	0.75	10/11/12	95 a	48 ab	0 c	75 ab	70 b	10,299 a	18.8 a
s-metolachlor	1.43	10/12/12	100 a	100 a	87 a	93 a	0 c	11,513 a	14.1 a
Pendimethalin	1.42	10/12/12	75 a	5 bc	33 bc	73 ab	0 c	12,991 a	18.8 a
Mesotrione	0.094	10/12/12	25 b	20 bc	68 ab	50 abc	0 c	11,149 a	18.6 a
Mesotrione	0.094	2/4/13	0 b	11 bc	90 a	65 ab	0 c	10,481 a	17.0 a
Fluroxypyr-bromoxynil	0.32	2/4/13	0 b	15 bc	40 abc	68 ab	95 a	1,558 b	6.5 b
Bromoxynil-MCPA	0.35	2/4/13	0 b	5 bc	68 ab	63 ab	0 c	10,057 a	15.9 a
Clopyralid	0.25	2/4/13	0 b	0 c	0 c	10 bc	0 c	11,534 a	18.1 a

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

[2] Preplant incorporated.

Table 6. Weed control, crop injury, dry biomass, and seed yield of ‘Linore’ flax planted October 11, 2012.[1]

			Annual bluegrass	Lesser-seeded bittercress	Ivy-leaved speedwell	Flax		
			2/18/2013	3/19/2013	3/19/2013	Injury	Dry biomass	Seed yield
	Rate	Date applied	Control			3/19/2013	8/14/2013	8/14/2013
	(lb ai/a)		(%)			(%)	(lb/a)	(bu/a)
Check	—	—	0 b	0 c	0 b	0 c	9,106 a	23.7 a
Trifluralin[2]	0.75	10/11/12	93 a	0 c	15 ab	35 b	9,530 a	27.9 a
s-metolachlor	1.43	10/12/12	100 a	85 a	98 a	0 c	7,689 a	26.7 a
Pendimethalin	1.42	10/12/12	93 a	41 b	93 a	0 c	9,166 a	26.2 a
Mesotrione	0.094	10/12/12	69 a	85 a	90 a	0 c	9,470 a	26.2 a
Mesotrione	0.094	2/4/13	1 b	89 a	95 a	0 c	9,389 a	21.0 a
Fluroxypyr-bromoxynil	0.32	2/4/13	12 b	36 b	31 ab	90 a	2,995 b	13.2 b
Bromoxynil-MCPA	0.35	2/4/13	0 b	66 ab	51 ab	0 c	8,438 a	24.8 a
Clopyralid	0.25	2/4/13	0 b	0 c	19 ab	0 c	7,730 a	25.4 a

[1] Means followed by the same letter are not significantly different (*P* = 0.05).
[2] Preplant incorporated.

Table 7. Crop injury, dry biomass, and seed yield of ‘Agatha’ flax planted March 13, 2013.[1]

			Flax		
			Injury	Dry biomass	Seed yield
	Rate	Date applied	6/11/2013	9/11/2013	9/13/2013
	(lb ai/a)		(%)	(lb/a)	(bu/a)
Check	—	—	0 d	3,462 a	4.0 a
s-metolachlor	1.43	3/18/13	0 d	3,774 a	4.7 a
Pendimethalin	1.42	3/18/13	0 d	3,426 a	5.0 a
Mesotrione	0.094	3/18/13	0 d	3,515 a	4.7 a
Mesotrione	0.094	5/31/13	24 b	3,337 a	3.9 a
Fluroxypyr-bromoxynil	0.32	5/31/13	65 a	2,052 a	0.1 b
Bromoxynil-MCPA	0.35	5/31/13	10 c	3,872 a	4.9 a
Clopyralid	0.25	5/31/13	0 d	3,212 a	3.4 a

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

Table 8. Weed control, crop injury, dry biomass, and seed yield of ‘Linore’ flax planted March 18, 2013.[1]

			Sharp-point fluvellin	Prostrate knotweed	----------------- Flax -----------------		
			--------- Control ---------		Injury	Dry biomass	Seed yield
	Rate	Date applied	7/8/2013	7/8/2013	6/11/2013	9/11/2013	9/13/2013
	(lb ai/a)		------------ (%) ------------		(%)	(lb/a)	(bu/a)
Check	—	—	0 b	0 b	0 c	4,140 a	12.1 a
s-metolachlor	1.43	3/18/13	31 b	75 a	0 c	4,202 a	14.29 a
Pendimethalin	1.42	3/18/13	48 ab	100 a	0 c	3,738 a	13.44 a
Mesotrione	0.094	3/18/13	35 b	100 a	0 c	4,327 a	13.66 a
Mesotrione	0.094	5/31/13	74 a	50 ab	18 b	3,480 a	12.46 a
Fluroxypyr-bromoxynil	0.32	5/31/13	25 b	100 a	40 a	2,391 b	1.027 b
Bromoxynil-MCPA	0.35	5/31/13	10 b	75 a	15 b	3,613 a	10.31 a
Clopyralid	0.25	5/31/13	13 b	0 b	0 c	3,096 ab	10.39 a

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

INFERRING CROP STAND AGE AND LAND USE DURATION IN THE WILLAMETTE VALLEY FROM REMOTELY SENSED DATA

G.W. Mueller-Warrant, S.M. Griffith, G.M. Banowetz, G.W. Whittaker, and K.M. Trippe

Introduction

Ongoing work is being conducted to classify agricultural crops, urban development, and forests in the Willamette Valley through analysis of ground-truth surveys and aerial imagery from 2004 through 2011. The objective is to lay the basis for answering fundamental questions regarding how landscapes are currently managed and how management may evolve in the future.

Previous remote sensing classifications defined 57 land use categories, which included 19 classes of annually disturbed agricultural crops, 20 classes of established perennial crops, 13 classes of forests and other natural landscape elements, and 5 classes of urban development (Mueller-Warrant et al., 2011; Mueller-Warrant et al., under review). The approach was successful in separating these four broad groups of classes from each other at 90 to 95% accuracy. Accuracy in classifying the land use categories varied substantially among the classes and over time, approaching 100% in the best cases and averaging between 64 and 77%.

If classification data are sufficiently accurate, the timing and duration of specific land use sequences can be determined. For a few long-lived crops and most urban development and forests, the eight-year extent of our remotely sensed classifications was too short to determine duration of land use sequences or detect long-term changes. For most crops, however, the eight-year period should be sufficiently long to include establishment, multiple years of production, and transition to rotational crops.

Defining the duration of specific land use practices at a site by identifying beginning and ending years of that land use serves several objectives. First, the process acts as a quality control procedure that finds a valid sequence of crops/land uses or proves that some of the classifications were in error (e.g., established tall fescue in 2005, established orchardgrass in 2006, and established tall fescue in 2007 would not be a feasible cropping sequence). Second, delineation of the landscape into areas that were either disturbed in a given year (to grow an annual crop or to plant a new stand of a perennial crop) or retained in an established perennial crop or other permanent land use is a key input into programs such as the Soil and Water Assessment Tool (SWAT) (Mueller-Warrant et al., 2012). Third, identification of the specific crop rotation patterns and stand durations common to the Willamette Valley enables us to detect outliers where stand lives of crops were unusually long or short. Such cases can be considered for on-site visits with cooperating growers to obtain detailed histories of field management practices, collect soil samples, and measure pest populations (insects, slugs, weeds, foliar and soil-borne diseases) to better understand the roles these factors play in forcing stands out of production or preventing successful establishment of new stands.

Method

The 57 land use categories were regrouped into 50 new categories by merging several cases of similar land use. Three categories of Italian ryegrass (full straw, normal fall-plant, and volunteer pasture) were merged; two categories of bare ground (bare ground in fall not otherwise classified in spring and fallow in spring) were merged; three categories of evergreens (Christmas trees, reforestation, evergreen forest) were also merged; and three categories of urban development (mixed grass and buildings, developed open space, and developed low intensity) were combined.

The reclassified rasters (images and derived data stored in a gridlike format) were compared one year to the next to identify locations where the crops or land uses did not change. The year-to-year rasters were combined to determine locations classified as the same category for multiple years up through a given final year. Raster summaries were used to calculate apparent stand ages for each class. As an alternative approach for data sequences that included 2011 classification results, the restriction that the ends of stand lives had to be identified based on change in land use classification between the final year of a stand and the following year was eliminated. This approach produced minimum stand age estimates because it could not guarantee that the sequence of identical land use would not continue beyond 2011.

Results

Our first objective was to conduct quality control tests of our methods to determine whether our stand age distributions were reasonable or whether they implied the presence of systematic problems in the individual year classifications. The most immediate problem that classification errors would cause is shortening of the apparent stand life/age. The stand ages calculated in Tables 1 and 2 are the number of consecutive years in which a given location was classified as growing the same crop or having the same land use. Our methods for calculating stand age did not include the establishment year for perennial crops.

Problems from misclassifications (such as the sequence perennial ryegrass/Italian ryegrass/perennial ryegrass) were common in our results. For example, only 27% of the Italian ryegrass acreage was even assigned a stand age, indicating that at least some crops classified as Italian ryegrass in one year were sandwiched between other crops, a fairly unlikely situation given that Italian ryegrass is commonly produced on the same fields from year to year (Table 1). Another cause for failure to define Italian ryegrass stand age is that our methods required detection of the apparent end of the string of consecutive crops, and much of the Italian ryegrass acreage in any year simply continued on as Italian ryegrass in the next year (e.g., 77% did so from 2010 to 2011). Despite this limitation, the Italian ryegrass cropping sequences that were identified included approximately even numbers of stands of all ages up to seven years, the maximum we could characterize.

Many of the annual crops and new seedings of perennial crops behaved as expected, with over 90% of the cases identified as single-year events for spring plantings of new grass seed crops, peas, and mint (classes 3, 41); fall plantings of grass seed and legume crops (classes 13, 14, 15, 40, 43); bush beans (class 35); and *Brassica* seed crops (class 55). Small numbers of second-year crops of wheat and meadowfoam were detected, but most of the wheat and meadowfoam crops were grown as single-year-production annuals.

In general, estimated ages for established stands of perennial crops seemed to indicate that too many were identified as single-year stands. Correcting this problem will probably require incorporating knowledge of previous classification of a location as a long-lived crop (e.g., pasture, orchard, blueberries, or vineyard) into subsequent classifications. Removal of single-year occurrences of crops such as Italian ryegrass between multiple years of other established grass seed crops will also help improve our estimates of stand ages of perennial crops.

Relaxing our restriction that land uses had to change in 2011 relative to 2010 to signify the end of a sequence of identical crops/land uses corrected most of the problems of missing classes. Considering all the identical land use sequences ending in 2011, we found that stand age was defined in over 90% of the cases for all but one of the annual disturbed crops. Age was defined in over 99% of the cases for seven of the crops (Table 3). Similarly, stand ages were defined in over 86% of the cases for all but one of the established perennial crops. Again, age was defined in over 96% of the cases for seven of the crops (Table 4). Among grass seed crops, orchardgrass and fine fescue had the largest fractions of stands at least 8 years in age.

Conclusions

The raw individual year classification data clearly possess problems limiting their ability to accurately define true stand ages for many crops in western Oregon. One very critical issue is the challenge of determining when the end of a stand has been reached. Many of the sequences of identical crops extended through 2011, the final year for which remote sensing classifications have been conducted. We have ground-truth data and remote sensing imagery for additional years up through the impending 2014 harvest, and incorporating classifications from those additional years should help better identify the ending time for many additional multiyear stands.

A second critical issue is the presence of single-year classification errors interrupting what would otherwise be recognized as a single longer stand rather than two shorter stands. Systematic approaches for solving this problem should begin with correction of the most obvious errors (such as a single year of one established perennial crop interspersed between multiple years of a different perennial crop) and continue on into more subtle questions of whether a particular land use makes sense as something that could occur in the year immediately prior to an established perennial crop being present. Even though correcting the most clearly obvious single-year errors will not fix all classification errors, doing so will substantially improve the accuracy of stand age measurements in many cases. More robust handling of individual year classification errors might also be achieved through inclusion of prior-year land use data in the classification process itself.

Accurate identification of beginning, end, and duration of multiple-year crop stands was successful in a large number of cases and could be used to find stands of particular ages for further evaluation and research. It will be necessary to improve the accuracy of stand age measurements before the data can be used to identify outliers (unusually long or short stand lives) that will be of particular research interest in terms of possible causes of the departures from normal. It will also be necessary to bring the classifications closer to the present because reasons for shorter or longer stand lives may disappear when fields are subsequently rotated into other crops.

In addition to guiding future agronomic research into factors causing shortened stand lives and difficulties in establishing new grass seed stands, our results may also help policymakers develop improved land use rules, regulations, and incentives based on more complete scientific knowledge of the on- and off-farm impacts of contrasting land use practices (annual versus perennial crops, short- versus long-term rotations, diversity versus simplicity of rotational crops). Sustainability of agriculture cannot be achieved without an effective combination of research, regulation, assessment, and ongoing reconsideration of policies affecting prices of crops and inputs, rules regarding use of inputs, and effective extension of research knowledge to producers. It is our goal to provide valuable contributions to that process through deeper understanding of the reasons for successes and failures experienced by western Oregon grass seed growers.

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Table 1. Apparent stand age of 16 crops with annual disturbance.

		--------------------- Apparent duration of repeated identical crops ---------------------							
Class No.	Crop/Land use category	Single year	Two years	Three years	Four years	Five years	Six years	Seven years	Total
		---------------- (% of total area classified in particular crop/land use) -----------------							
1	Bare ground in fall or true fallow	34.4	10.2	5.3	3.6	3.0	2.8	4.8	64.2
2	Full straw Italian ryegrass	9.0	3.8	2.3	2.6	2.9	2.6	4.3	27.6
3	Spring-plant new grass seed stands	92.3	3.3	0.0	0.0	0.0	0.0	0.0	95.7
13	Fall-plant perennial ryegrass	94.2	2.3	0.0	0.0	0.0	0.0	0.0	96.5
14	Fall-plant tall fescue	99.9	0.0	0.0	0.0	0.0	0.0	0.0	100.0
15	Fall-plant clover	92.8	3.0	0.0	0.0	0.0	0.0	0.0	95.8
16	Wheat and oats	58.5	8.8	3.1	0.3	0.1	0.1	0.1	71.1
17	Meadowfoam	72.6	10.1	1.1	0.3	0.0	0.0	0.0	84.2
27	Corn and sudangrass	71.0	3.2	0.1	0.0	0.0	0.0	0.0	74.2
35	Beans	90.1	3.0	0.2	0.1	0.0	0.0	0.0	93.3
36	Flowers	80.1	0.6	0.0	0.0	0.0	0.0	0.0	80.7
40	Other fall-plant/ no-till grass seed crops	99.7	0.0	0.0	0.0	0.0	0.0	0.0	99.7
41	Spring-plant peas or other unidentified	95.4	1.3	0.0	0.0	0.0	0.0	0.0	96.8
42	New planting hops, filberts, blueberries	87.9	2.5	0.0	0.0	0.0	0.0	0.0	90.4
43	New planting alfalfa or vetch	95.9	0.8	0.0	0.0	0.0	0.0	0.0	96.8
55	Brassicaceae	91.4	2.5	0.0	2.1	0.0	0.0	0.0	96.0

Table 2. Apparent stand age of 20 established perennial crops.

		------------- Apparent age of established stands beyond the seeding year -------------							
Class No.	Crop/Land use category	Single year	Two years	Three years	Four years	Five years	Six years	Seven years	Total
		------------------ (% of total area classified in particular crop/land use) ----------------							
4	Established perennial ryegrass	27.4	14.8	8.4	4.4	2.8	2.4	2.3	62.6
5	Established orchardgrass	42.8	7.3	2.6	2.2	1.5	3.0	2.8	62.2
6	Established tall fescue	19.7	6.8	6.6	6.2	4.8	3.4	2.2	49.6
7	Pasture	33.8	10.1	3.5	1.7	1.9	2.0	1.0	53.9
8	Established clover	56.9	13.7	2.6	1.1	0.0	0.0	0.0	74.3
9	Established mint	35.1	12.5	19.2	11.7	2.3	0.0	0.0	80.9
10	Hay crop	46.3	10.6	3.6	2.3	1.3	1.2	1.1	66.4
18	Established bentgrass	56.8	8.7	4.3	2.4	4.6	3.1	0.0	79.9
19	Established fine fescue	29.6	5.7	3.5	4.2	3.1	4.9	4.6	55.5
21	Wild rice paddies	21.1	1.6	0.0	0.0	0.0	0.0	0.0	22.7
22	Wetlands restoration	62.7	3.9	0.8	0.0	0.0	0.2	0.0	67.6
23	Established alfalfa	78.8	4.4	0.1	0.6	0.2	0.1	1.8	86.0
24	Established blueberries	49.7	1.1	0.4	0.0	0.1	0.0	0.0	51.4
25	Filberts	50.8	8.2	2.5	0.9	0.4	0.8	2.7	66.3
26	Caneberry	54.0	10.8	2.3	0.6	0.3	0.6	0.4	69.1
28	Nursery crops	36.5	10.3	4.6	2.3	1.3	1.7	0.4	57.1
29	Orchard crops (apple, cherry)	47.3	3.6	0.8	0.2	0.8	0.2	0.0	52.7
32	Vineyard	53.1	9.5	4.3	1.7	2.3	2.4	1.5	74.8
38	Established hops	55.9	6.5	1.5	0.5	1.4	0.0	0.5	66.3
56	Strawberries	38.6	5.3	14.5	9.5	0.0	0.0	0.0	67.9

Table 3. Minimum apparent stand age from 2011 data only of 16 crops with annual disturbance.

		--------------------- Apparent duration of repeated identical crops ---------------------								
Class No.	Crop/Land use category	Single year	Two years	Three years	Four years	Five years	Six years	Seven years	Eight years	Total
		----------------- (% of total area classified in particular crop/land use) -----------------								
1	Bare ground in fall or true fallow	62.8	17.6	2.7	4.0	1.3	1.4	0.5	7.0	97.3
2	Full straw Italian ryegrass	34.5	9.8	3.5	2.1	2.8	3.6	1.1	42.1	99.5
3	Spring-plant new grass seed stands	97.1	1.9	0.0	0.0	0.0	0.0	0.0	0.0	99.0
13	Fall-plant perennial ryegrass	96.6	1.3	0.0	0.0	0.0	0.0	0.0	0.0	97.9
14	Fall-plant tall fescue	95.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	95.5
15	Fall-plant clover	97.7	1.6	0.0	0.0	0.0	0.0	0.0	0.0	99.3
16	Wheat and oats	70.2	19.7	4.4	2.6	0.6	0.0	0.0	0.6	98.1
17	Meadowfoam	93.3	6.2	0.0	0.0	0.0	0.0	0.0	0.0	99.5
27	Corn and sudangrass	69.0	18.1	12.1	0.0	0.3	0.0	0.0	0.0	99.6
35	Beans	95.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	95.2
36	Flowers	65.8	16.6	0.3	0.0	0.0	0.0	0.0	0.0	82.7
40	Other fall-plant/no-till grass seed crops	99.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	99.6
41	Spring-plant peas or other unidentified	91.6	0.4	0.1	0.0	0.0	0.0	0.0	0.0	92.0
42	New planting hops, filberts, blueberries	94.9	3.1	0.0	0.0	0.0	0.0	0.0	0.0	97.9
43	New planting alfalfa or vetch	96.9	0.5	0.0	0.0	0.0	0.0	0.0	0.0	97.4
55	Brassicaceae	99.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.7

Table 4. Minimum apparent stand age from 2011 data only of 20 established perennial crops.

		-------------------- Apparent duration of repeated identical crops --------------------								
Class No.	Crop/Land use category	Single year	Two years	Three years	Four years	Five years	Six years	Seven years	Eight years	Total
		----------------- (% of total area classified in particular crop/land use) -----------------								
4	Established perennial ryegrass	54.4	25.3	6.5	3.7	2.0	1.2	0.5	5.2	98.9
5	Established orchardgrass	65.6	5.2	8.9	2.6	1.1	0.3	0.4	14.8	98.9
6	Established tall fescue	22.7	46.2	9.9	8.5	5.4	2.1	0.4	4.2	99.3
7	Pasture	57.1	5.1	1.3	10.0	4.4	1.6	3.5	5.2	88.2
8	Established clover	79.2	16.2	3.2	0.6	0.0	0.0	0.0	0.0	99.3
9	Established mint	69.5	13.0	10.7	3.5	0.0	0.0	0.0	2.4	99.1
10	Hay crop	62.7	12.3	7.7	1.6	1.3	0.9	0.4	2.1	88.9
18	Established bentgrass	80.7	4.7	3.8	2.4	0.0	0.0	0.0	5.1	96.7
19	Established fine fescue	45.1	12.8	9.1	4.6	4.7	3.3	0.0	13.8	93.4
21	Wild rice paddies	32.2	49.1	6.9	2.0	2.9	1.1	0.0	0.6	94.8
22	Wetlands restoration	29.6	33.2	4.4	27.3	0.0	0.0	0.0	0.0	94.4
23	Established alfalfa	86.0	5.0	0.9	0.0	0.0	0.0	0.0	0.0	91.9
24	Established blueberries	77.9	11.5	2.5	0.7	0.2	0.9	0.0	1.2	94.9
25	Filberts	58.7	6.1	7.8	5.6	0.3	3.4	0.3	5.9	88.1
26	Caneberry	76.6	3.8	3.1	1.3	0.2	0.6	0.0	1.0	86.7
28	Nursery crops	64.4	8.0	5.4	4.7	1.1	1.2	0.8	7.4	93.0
29	Orchard crops (apple, cherry)	63.4	4.0	0.2	0.2	0.1	0.0	0.0	0.0	67.9
32	Vineyard	56.7	9.1	5.4	8.4	1.1	0.7	0.5	9.7	91.5
38	Established hops	66.2	14.1	3.7	0.7	0.0	0.0	0.0	4.2	89.0
56	Strawberries	93.5	3.7	0.0	0.0	0.0	0.0	0.0	0.0	97.2

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Business Address

Oregon Seed Council
494 State Street, Suite 220
Salem, OR 97301

Tel: (503) 585-1157
FAX: (503) 585-1292
E-mail: roger@rwbeyer.com
www.OregonSeedCouncil.org

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