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POSTHARVEST RESIDUE MANAGEMENT PRACTICES DO NOT IMPACT CARBON STOCKS IN TALL FESCUE SEED CROPS

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Introduction

There is keen interest among Oregon grass seed producers to understand how crop management practices, such as tillage and residue management, influence the amount of carbon (C) stored in soils. This interest is related to our growing understanding of how organic C regulates key soil functions, including increased water- and nutrient-holding capacity, reduced mobility of pesticides, increased biological activity, and improved soil structure. As soil C is intrinsically related to soil function, improvements in function can cascade and ultimately lead to enhanced productivity, reduced environmental footprints, and improved resilience to droughts and other extreme weather events.

Interest in understanding the relationship between crop management practices and soil C is also driven by the recent emergence of voluntary C markets. Grass seed producers may have the potential to participate in C markets by implementing practices that are known to favor soil C storage. Producers could then potentially sell C offsets or receive C credits for on-farm reductions in greenhouse gas emissions.

Despite the potential agronomic and economic benefits associated with increasing soil C, our understanding of the effects of residue management practices on soil C storage in the Willamette Valley is limited. Generalizations regarding the effect of agronomic management practices on soil C in other cropping systems do not seem to extend to grass seed production in the Willamette Valley.

For example, in annual cropping systems, reduced tillage typically favors the accumulation of soil C (Nunes et al., 2020). However, in the Willamette Valley, a recent 9-year study concluded that tillage practices and establishment methods had little impact on soil C in annual ryegrass seed production (Chastain et al., 2017).

Similarly, in other cropping systems, returning crop residues to the soil generally increases C stocks. Again, in the Willamette Valley, the response of soil C to residue inputs is less predictable. For example, Griffith et al. (2011) reported that chopping and leaving the residue of tall fescue to decay increased surface soil C at only one of three Willamette Valley field sites over 6 years. Likewise, a recent survey of 28 tall fescue fields found that returning crop residue had no effect on the amount of organic matter or active C in the soil (Verhoeven et al., 2021).

While the unpredictable response of soil C to management practices may be attributed to inherent soil properties (e.g., texture and drainage class) or crop characteristics (e.g., rooting depth and perennial nature), it may also be attributed to a lack of experimental data. Most studies that have investigated soil C in grass seed production systems have measured C dynamics in the top 6–8 inches of the soil profile. To fully account for C, a comprehensive assessment of soil C that includes measurements of C in deeper soil horizons (0–39 inches) is necessary. Accounting for C inputs from above-ground (shoots) and below-ground (roots) biomass is another key aspect of C stock assessment that has not previously been included in estimates of soil C stocks in the Willamette Valley.

Therefore, the primary goal of this study was to expand our understanding of C dynamics across the soil profile by assessing the effects of stand age and postharvest residue management practices on C stocks in tall fescue (*Schedonorus arundinaceus* (Schreb.) Dumort.) seed crops. Data for grass seed systems need to be put in context with data from other Willamette Valley land-use scenarios. To this end, we also sampled a limited number of fields with more highly disturbed soils (for example, those with a history of annual tillage), as well as uncultivated natural areas.

Materials and Methods

Field selection

A total of 24 tall fescue fields were sampled across the Willamette Valley. In 12 of these fields, the postharvest straw was chopped and allowed to decompose in the field (“full straw”). In the other 12 fields, the residual straw residue was baled and removed from the field (“bale”). These residue management practices were carried out for at least 75% of the stand years. Within each management category, the fields were further subdivided by age: six fields had stands that were

2–4 years old (“young”), and six fields had stands between 5 and 20 years old (“old”).

Soil and plant sampling

Soil maps from the Natural Resources Conservation Service were used to identify the dominant soil series. Soil samples (0- to 39-inch depth) were collected between February and April of 2021 using an ATV-mounted hydraulic probe with a 2-inch diameter coring tube (Giddings Machine Co., Windsor, CO) and were analyzed for total soil C and bulk density. In each field, three transects were established within the dominant soil series. Within each transect, three cores were collected for a total of nine cores per field. Following collection, soils were kept at 4°C until processed for total C, bulk density, and phospholipid fatty acid analysis.

Additional soil and root samples were collected in the spring of 2021 for microbial biomass and root C analysis. For microbial biomass, at each sampling point, a slice of soil was collected with a shovel (0–12 inches), and the three slices per transect were composited and mixed. A subsample of the composited slices was placed into a 1-gal plastic bag. Roots were collected from the center of tall fescue rows using a sharpshooter shovel, and a soil knife was used to trim the sample (2-inch x 5-inch x 12-inch slice). After collection, all samples were stored in individual 1-gal plastic bags at 4°C until processed.

In June 2021, at plant physiological maturity, above-ground tall fescue biomass was collected by harvesting a 1 ft^2 in-row quadrat using rice knives. Samples were collected across the same transects and sampling points as in the soil and root sampling (three samples/transect). Row spacing for each field was measured to convert individual plant biomass and C values to per-acre estimates.

Another set of soil samples was collected in the summer of 2021 from three annually tilled fields and three undisturbed natural areas. These fields were used to compare the soil C stocks in soils with contrasting levels of soil disturbance but similar soil types as those sampled in the tall fescue fields. The 10-year cropping history of annually disturbed fields consisted of: (1) a winter wheat/red clover rotation, (2) a winter wheat/vetch/annual ryegrass/pea rotation, and (3) a field that was in winter wheat in 2021 but had been continuously planted to corn for the previous decade. The uncultivated areas consisted of a grassy area at the edge of a field near a homestead and two local natural preserves with permanent grasslands. Soil cores from a 0- to 39-inch depth were collected as described earlier, with the exception that two samples were collected and composited from each transect.

Soil and plant processing and analysis

Soil cores were divided into two sections (0–12 and 12–39 inches) and air-dried. Soils were weighed to estimate bulk density and composited by transect to obtain three samples per field for each of the sampled depths. Samples were then sieved through a 2-mm mesh screen, and pebbles or plant fragments larger than 2 mm were discarded. Soil samples were then oven-dried at 221°F for 24 hours and weighed for total C analysis by combustion (LECO, 828 series, St. Joseph, MI).

To assess soil microbial biomass and microbial community structure, samples were shipped to Microbial ID, Inc. (Newark, DE) for phospholipid fatty acid analysis.

A subsample of 108 root samples (corresponding to 12 fields; 3 from each straw and age management combination) were washed over a 1-mm sieve to remove the soil. All plant biomass (below-ground and above-ground) was oven-dried at 149°F for 48 hours, composited by transect, ground, weighed in triplicate subsamples (0.25 g each), and analyzed for total C as above.

C stock calculation and statistical analysis

Total C stocks in the soil cores were calculated using the following equation:

$$C_{\text{stock}} = C_{\text{content}} \cdot (1 - \text{mass proportion}_{\text{coarse}}) \cdot \rho \cdot d$$

> where C_{content} is the mass proportion of soil C in the soil, mass $\text{proportion}_{\text{coarse}}$ is the mass proportion of the coarse soil to the whole soil sample, ρ is the bulk density of the whole soil, and d is the depth.

The effects of straw residue management and stand age on soil were evaluated using two-way ANOVAs and Tukey HSD posthoc analyses in R; data were log-transformed when assumptions of normality or homogeneity of variances were not met. Microbial biomass and community parameters were evaluated using a Kruskal-Wallis analysis.

Results and Discussion

There was no difference in soil C stocks at the 0- to 12-inch depth between postharvest residue management practices ($P = 0.11$) or between old and young stands ($P = 0.42$, Table 1). We expected that C stocks would increase with stand age; however, this was not the case, and no significant correlation was observed between the two variables (data not shown). Similar trends were observed in the deeper soil profile. Soil C stocks at the 12- to 39-inch depth were not affected by age category ($P = 0.19$) or postharvest residue management ($P = 0.37$). Average values of soil C stocks for each treatment at the different soil depths are shown in Table 1.

Immediately before harvest, above-ground biomass and corresponding above-ground C stocks were highest in young, baled fields and lower in the other treatments ($P = 0.006$, Table 1). Decreased above-ground biomass in older fields and in young, full-straw fields could be related to higher pest pressure or to limited access to sunlight during early growth stages of tall fescue in full-straw managed fields.

Below-ground biomass increased with stand age ($P < 0.001$) but was not influenced by postharvest residue management practices ($P = 0.68$). Percent C in root tissue decreased over time from an average of 37% to 32% ($P = 0.015$), but overall C stocks remained higher in old stands compared to young stands ($P = 0.008$, Table 1).

Measurements of phospholipid fatty acids are used to assess the total microbial biomass and to broadly categorize microbial community composition (i.e., fungi, bacteria, actinomycetes). Microbial biomass was not different between postharvest residue management practices in young fields ($P = 0.055$, Table 1). Microbial biomass increased with stand age in the retention fields but not in baled fields. The increase in microbial biomass in older stands with a full straw return was driven primarily by an increase in total bacterial populations ($P = 0.003$). Fungal biomass was not altered by stand age or postharvest residue management practices.

Total C stocks (soil, above- and below-ground biomass) of tall fescue stands were not different regardless of stand age or postharvest residue management practices (Table 1 and Figure 1). The overall average C stock was 75.6 ton/acre. With more than 150,000 acres planted in tall fescue in the Willamette Valley, total C stocks for this cropping system would be greater than 11.6 million tons.

In addition to understanding how C stocks respond to management practices, it is also important to understand how they respond to cropping systems. For example, we expect that annually tilled row or field crops accumulate less soil C than perennial grass seed crops. However, given that soil C does not seem to respond to repeated tillage in annual ryegrass crops (Chastain et al., 2017), this assumption could be erroneous in Willamette Valley conditions.

We also measured soil C stocks of natural undisturbed areas and annually tilled soils (Figure 2). Average soil C stocks at the 0- to 12-inch depth differed across a land disturbance gradient. Soil C stocks of tall fescue (41 ton/acre) were lower than in uncultivated natural areas (50 ton/acre) but higher than in annually tilled crops (33 ton/acre) from similar soil types in the Willamette Valley. However, at the 12- to 39-inch depth, tall fescue and annually tilled crops had similar soil C stocks (24 and 23 ton/acre, respectively), and these were significantly lower than soil C stocks of undisturbed natural areas (37 ton/acre).

Table 1. Carbon (C) stocks in soil, C stocks in above- and below-ground biomass, and microbial biomass at plant physiological maturity immediately prior to seed harvest.[1]

	----- Young (2–4 years) -----		------- Old (> 5 years) -------	
	Bale	Full straw	Bale	Full straw
Soil C stocks, 0-12 inch[2]	40.1 ± 2.4	42.0 ± 1.5	40.3 ± 2.1	45.2 ± 3.2
Soil C stocks, 12-39 inch[2]	28.7 ± 1.6	25.2 ± 1.8	30.6 ± 2.1	34.6 ± 5.8
C stocks in AG biomass[2]	3.8 ± 0.4	2.2 ± 0.2	2.9 ± 0.3	2.8 ± 0.3
C stocks in BG biomass[2]	0.9 ± 0.1	1.2 ± 0.1	1.7 ± 0.3	1.7 ± 0.2
Microbial biomass[3]	88.2 ± 9.1	79.9 ± 10.3	94.0 ± 12.2	127.4 ± 34.0

[1] Values shown are the mean ± standard error.

[2] ton/acre

[3] nmole/g soil

Conclusion

The results of our study suggest that postharvest residue management practices do not drive meaningful changes in C stocks in Willamette Valley tall fescue seed fields. These results agree with previous examinations of C dynamics in tall fescue seed crops (Griffith et al., 2011; Verhoeven et al., 2021). These results are a bit puzzling since it is estimated that straw contributes significant amounts of C per acre (Hart et al., 2012). Our results suggest that this C is not accumulating in the soil, but its fate remains unknown. One possible explanation is that data collected from on-farm measurements and surveys, including the data presented here and in previous examinations, is too variable to directly connect management practices with C outcomes. Another hypothesis is that microbial populations under full-straw retention cycle carbon rapidly, returning it to the atmosphere. Long-term studies of Willamette Valley grass seed cropping systems are needed to fully account for changes in C stocks.

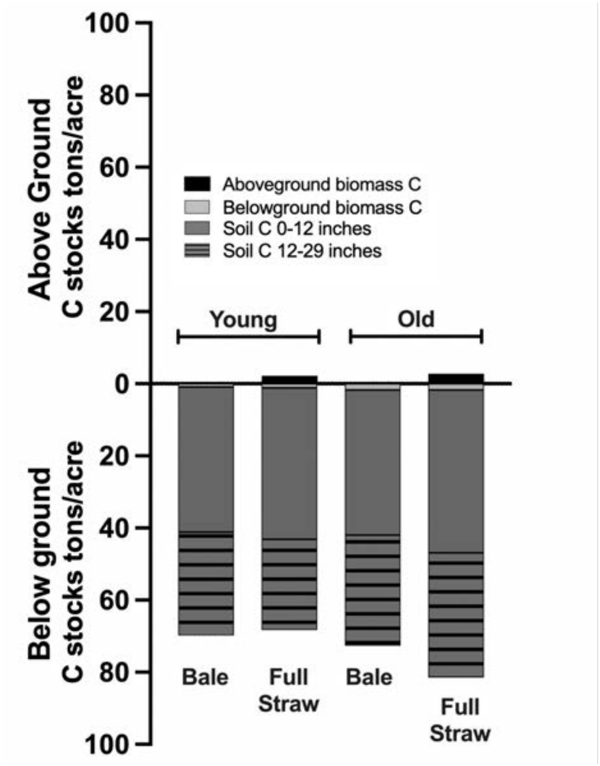

Figure 1. Carbon (C) stocks in tall fescue seed fields according to age and postharvest residue management practices. In baled fields, above-ground C contributions are assumed to be negligible because straw is removed postharvest. Upper bars represent C contributions from above-ground biomass (black). Lower bars represent contributions of root carbon (light gray), soil C in the top 0–12 inches (solid dark gray), and soil C in the 12- to 29-inch depth (striped).

While our results suggest that baling does not affect C stocks, other fertility and soil health consequences of baling should be considered in decisions regarding postharvest straw management. It is well known that baling depletes plant-available K (Hart et al., 2012), and it may reduce microbial biomass and soil aggregate stability (Table 1; Verhoeven et al., 2021). These losses need to be balanced by the reality that full straw may return lower seed yields and increase pest and pathogen pressure (Hart et al., 2012). Oregon State University Extension publications that outline the economic and agronomic trade-offs of postharvest residue management practices are available (Hart et al., 2012).

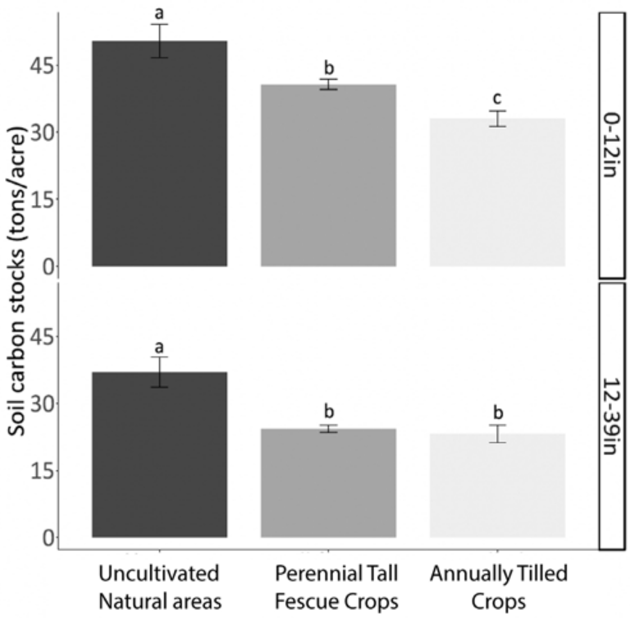

Figure 2. Average soil carbon (C) stocks in the 0- to 12-inch and 12- to 39-inch soil depths in different land uses. Error bars show standard error of the mean. Different letters indicate that average values are statistically different at the 95% confidence level.

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FERTILIZER NITROGEN USE EFFICIENCY AND FATE IN TALL FESCUE SEED PRODUCTION

E.C. Verhoeven and D.R. Carrijo

Introduction

Optimizing the timing and rate of fertilizer nitrogen (N) inputs is critical to achieving high crop yields and profitability, while minimizing the risk of environmental losses. In years with mild or warm January temperatures, the OSU-recommended growing degree day (GDD) mark to begin fertilization can be reached as early as the end of January for tall fescue (200 GDD). While extensive work has been done to develop current OSU fertilizer recommendations for timing and rate of spring N, there have been questions about how much early-season (January) N may be taken up by the plant, remain in the soil, or be lost via leaching when we have early GDD accumulation followed by a period of cooler temperatures prior to rapid growth later in the spring. Past research has shown that peak N uptake typically occurs in late March to early April in tall fescue (Anderson et al., 2014).

While developing recommendations to maximize plant N uptake, it is also critical to minimize losses of N into the environment. To date, previous studies in the Willamette Valley have primarily focused on N fertilizer fate/loss in the Calapooia watershed in the southern Willamette Valley. This focus was due to the discovery of nitrate levels in wells and groundwater in portions of the Calapooia watershed that persistently exceeded the EPA drinking water standard of 10 mg/L. As a result, a groundwater management area was declared in 2004.

Research in this area has found that nitrate-N leaching can vary widely among crops, years, and fields. A study that included fields in vegetable seed, hazelnut, blueberry, mint, and grass seed production estimated annual nitrate-N leaching rates between 0.5 to more than 250 lb ac^{-1} (Compton et al., 2021). Within this study, five grass seed fields were included (an annual ryegrass field and two perennial and tall fescue fields). Annual nitrate leaching from the grass seed fields ranged from 9 to 134 lb ac^{-1} yr^{-1} and occurred mainly in the fall and early winter. Similarly, another study that looked at modeled crop N losses across the Calapooia watershed found that nitrate losses and export to streams were highest in the fall and winter (Lin et al., 2019).

The Calapooia watershed is characterized by a higher proportion of poorly drained soils than are other parts of the Willamette Valley, which may affect leaching, runoff, and N losses in the area. More research is needed in the Willamette Valley, across a broader diversity of soils, to better understand tall fescue plant N utilization and potential N loss from early-season fertilizer applications, as well as postharvest losses during the subsequent fall and early winter. In addition, a need exists to generate more comprehensive data on tall fescue N use efficiency (NUE, i.e., the percentage of fertilizer N recovered in above-ground plant material at harvest) and N fate under typical management systems for tall fescue seed production.

Various methods exist to calculate the NUE of a cropping system and to evaluate N loss from the soil. In this study, we utilized ^{15}N isotope-labeled urea fertilizer, which acts like a dye and allows the tracing of N in the plant and soil system. In this method, any applied N not recovered in the plant or crop rooting zone is assumed to be lost into the environment (leaching, surface runoff, volatilization, or denitrification). Estimates of NUE in major commodity crops (corn, wheat, and rice) range between 30 and 50%, with estimated annual fertilizer losses often in the range of 10–30% (Quan et al., 2021; Zhang et al., 2021). Better estimates of NUE in current grass seed production systems will help growers better understand their crops' current NUE and whether there is potential for improvement.

The overall objectives of this study were two-fold:

- To determine the optimal timing for spring N application to tall fescue in order to maximize uptake and minimize losses.
- To determine the NUE of typical tall fescue systems, across different soil types of the Willamette Valley, and to estimate environmental losses during the growing season and in the fall after harvest.

Materials and Methods

Three identical on-farm trials were conducted in second-year tall fescue fields, representing two relatively well-drained soils and one poorly drained soil (Table 1). The different levels of soil drainage were chosen to represent typical tall fescue systems in the Willamette Valley. At each field site, plots (12 feet x 4 feet) were established for application of the labeled fertilizer.

Table 1. Mapped soil series, soil drainage class, and baseline properties of each study site.[1]

Site	Soil series	Soil drainage	Soil sample depth	Sand	Silt	Clay	C	N	pH	Bulk density
				(%)	(%)	(%)	(%)	(%)	(1:1 H_2O)	(g/cm^3)
St. Paul	Woodburn	Moderately well drained	0–6 in	15	63	22	1.97	0.16	6.94	1.38
			6–12 in	15	64	22	1.47	0.14	6.60	1.28
Silverton	Salkum	Well drained	0–6 in	23	51	26	3.09	0.23	7.03	1.24
			6–12 in	20	48	32	1.81	0.14	6.19	1.29
Shedd	Holcomb/ Dayton	Somewhat to poorly drained	0–6 in	10	66	24	2.80	0.23	6.71	1.28
			6–12 in	12	62	26	2.03	0.18	5.84	1.26

[1] Soil properties were determined from composite samples taken at each site and analyzed at the Soil Health Lab at Oregon State University.

A ^{15}N-labeled urea fertilizer solution was applied at a total rate of 140 lb N/acre at three timings: early (230 GDD), late (365 GDD), and a split application (70 lb N/acre at both 230 and 365 GDD). According to industry and OSU standard practices, GDD was calculated beginning January 1 using a base temperature of 0°C. Different concentrations of fertilizer solutions were made by dissolving urea enriched with 2.3 atom% of ^{15}N in deionized water. A total of 1 gal was applied to each plot using a fine-nozzle watering can. At each site, growers also applied 40–60 lb N/acre in the fall following harvest as unlabeled urea.

Plant (above-ground) and soil (0- to 6-inch and 6- to 12-inch) samples were taken monthly at four dates until harvest. Final harvest samples were taken at physiological maturity (June 22–June 24, 2020). All sites were sampled again in January 2021, referred to as "postharvest." The harvest and postharvest sampling included sampling of the roots + crown down to 6 inches and an additional deeper soil sample at 12–18 inches. The postharvest sampling in January detected the presence of only the labeled fertilizer applied the previous spring.

Fertilizer recovery in plants and soil was determined with standard calculations for isotope tracer studies, which enabled the amount of fertilizer to be determined in the soil and plant at each sampling date. Climate data associated with each site was drawn from the PRISM Climate Group. The PRISM Climate Group uses spatial interpolation to model weather variables at a 4-km grid scale from local weather station data. All data were analyzed with a linear mixed effects model using repeated measures.

Results and Discussion

Across all three sites, there was no effect of fertilizer application timing (early, late, or split) on total plant N uptake (Figure 1) or estimated fertilizer N losses (data not shown). We also observed few differences among the sites, and there was no effect of soil type or drainage on plant N uptake or N losses in the year of the study (data not shown). Both of these results were in contrast to our hypothesis that increased N loss would result from early N application and would be more extensive in poorly drained soil.

On average, across sites and treatments, 57% of spring-applied N was recovered in the above-ground biomass at harvest, equating to NUE of 57% (Table 2). For most commodity grain systems, the NUE is generally between 30 and 50%, so the tall fescue systems in this study were comparatively more efficient at utilizing N fertilizer.

It should be noted that in the year of study February was quite dry, with about 3 inches less precipitation than normal (about half of the normal amount). This may have reduced leaching and runoff. Weather conditions in February are considered favorable for leaching loss of early N applications because plant growth is still relatively low. However, we believe the relatively high NUE comes not from uncharacteristically low losses but from the ability of tall fescue to scavenge soil N due to an extensive root system and to the capacity of Willamette Valley soils to retain and cycle N due to their relatively high organic matter content.

By harvest, 57% of the total fertilizer N applied was contained in the above-ground plant tissue, with 9% in

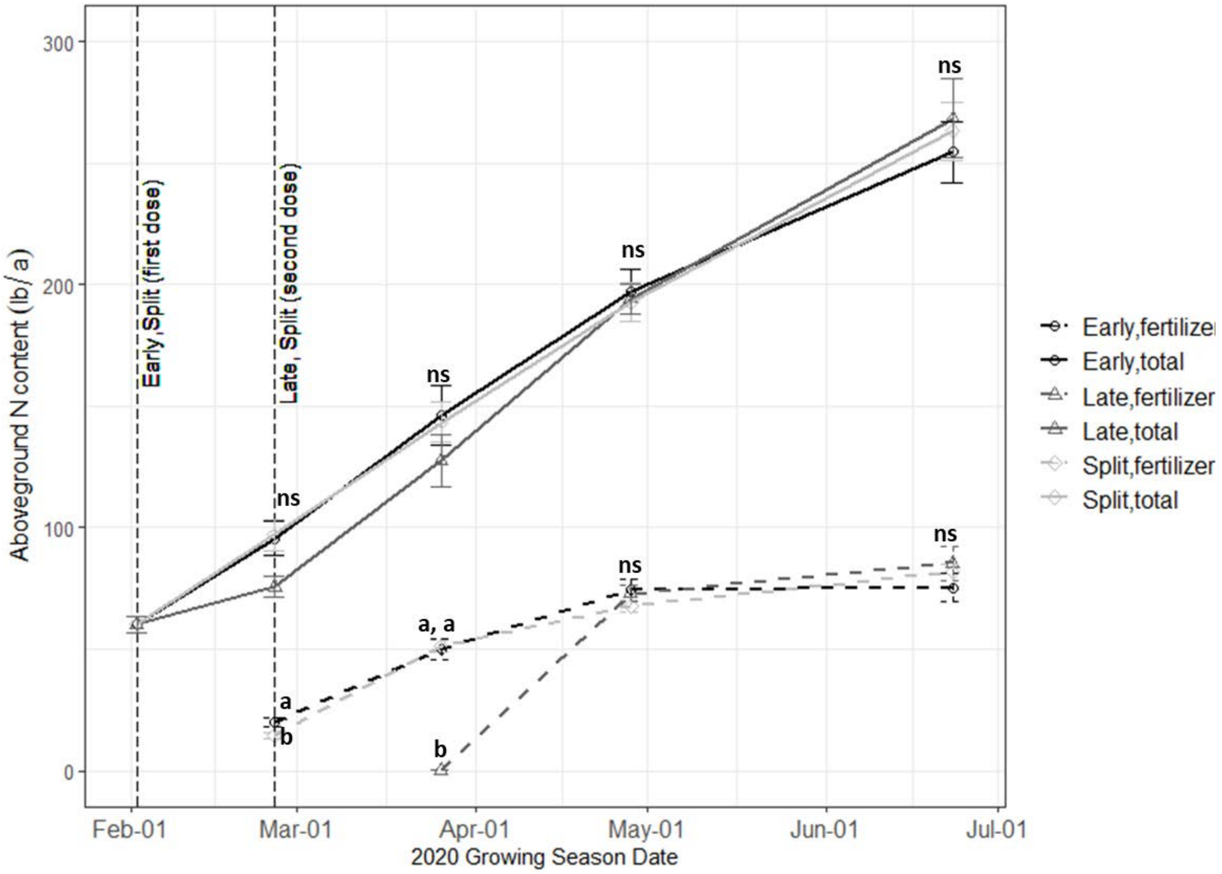

Figure 1. Total (solid lines) and fertilizer-derived nitrogen (N) (dashed lines) content in above-ground biomass over time. Values were averaged across the three locations, as there were no interactions between treatment, location, and time. Vertical lines indicate N fertilizer timings; N applications were made immediately after sampling on each date. At each sampling time, different letters within total or fertilizer-derived N indicate significant differences ($P < 0.05$) between treatments. Error bars indicate standard error of means. ns = no significant difference.

roots + crown, and 24% in the soil (0–18 inches). Most of the applied N remained in the top 6 inches of soil at harvest (Table 2). While 57% of applied N ended up in the above-ground biomass at harvest, this represented only 31% of the total N in the above-ground plant biomass and indicates that the soil was able to provide the majority of plant N needs, almost 70%. The high capacity of soils in this study to mineralize and supply N may be due to relatively high organic matter and to a buildup of organic N.

Plant uptake of applied N leveled off by the end of April, and most N accumulation in plant biomass after May appeared to be supplied by mineralization from soil organic matter (Figure 1). The ability of soil to supply N depends on the amount of total or organic N in

Table 2. Quantity and percent of applied fertilizer nitrogen (N) in each measured component of the system at harvest.

Component	Applied N	% of total applied N
	(lb/a)	(%)
Above-ground biomass (leaves + seeds)	80	57
Crown + roots	13	9
Soil (0–6 in)	22	16
Soil (6–12 in)	9	6
Soil (12–18 in)	2	2
Estimated loss	14	10

the soil and the rate at which this N is mineralized and converted to plant-available forms by microorganisms.

Nitrogen mineralization rates were not measured in this study, but it appears that mineralization rates must have increased in May as soil temperatures warmed because uptake and accumulation of N in above-ground biomass continued after uptake of labeled fertilizer N reached a plateau. Above-ground biomass N accumulation was slightly reduced in the late application treatment in March and April, but these reductions did not persist later into the season (Figure 1). Seed yields were not measured in this study, but there were no differences in total above-ground biomass at harvest due to N application timing.

At harvest, only 10% of applied N could not be recovered and was considered lost to the environment through leaching, denitrification, or volatilization (Table 2).

Although N leaching was not directly measured in this study, we did not see evidence of appreciable applied N movement down the soil profile, and we conclude that leaching of spring-applied N was low. Previous research has shown that applied N that remains in the soil after harvest may be lost through surface runoff or leaching from fall and winter precipitation (Lin et al., 2019; Compton et al., 2021). We did not find that to be the case in this study. When we sampled again in January 2021, the same amount of fertilizer N that was in the system at harvest remained in the system approximately 1 year after fertilizer application.

As noted above, 24% of fertilizer N remained in the soil at harvest, most of it in the top 6 inches (Table 2). This and the fact that the soil could supply the majority of plant N uptake indicates there may be potential to reduce fertilizer N inputs without reducing yields in established tall fescue. Timing of N application had no effect on N uptake or loss, nor was it influenced by study site (poorly to well-drained soils). Overall, the results from this study suggest flexibility for N management in tall fescue seed production regarding early applications and the potential to reduce application rates.

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EVALUATION OF CHLORMEQUAT CHLORIDE PLANT GROWTH REGULATOR ON DRYLAND PERENNIAL RYEGRASS SEED CROPS

N.P. Anderson and D.J. Maliszewski

Introduction

Plant growth regulators (PGRs) have been an important management tool utilized by grass seed growers worldwide for several decades. They have been used successfully to reduce lodging and increase seed yield in several cool-season grass species, including perennial ryegrass (*Lolium perenne* L.).

In Oregon, perennial ryegrass seed crops are grown on approximately 63,000 acres, and production is valued at nearly $100 million. However, production acres of this important cool-season grass seed crop have decreased by approximately 31% over the past ten years (Anderson, 2022). This reduction in production area is a result of increased input costs, higher pest pressure, and decreased stand longevity compared to other cool-season grass species that can be grown in the same environment. Thus, it is important to look for new management practices that may help overcome the economic challenges and improve future production opportunities for this important grass seed crop in Oregon.

Stem elongation in grasses is promoted by gibberellic acid (GA), but this elongation can be counteracted by the application of PGRs (Rademacher, 2015). There are three different groups of GA-inhibiting PGRs, two of which are examined in this study. One of these groups of PGRs block GA metabolism by inhibiting cyclase activities in the early stages of GA biosynthesis (onium compounds), while another works in late stages of GA biosynthesis by inhibiting dioxygenase reaction in blocking 2-oxoglutaric acid as a catalyst (acylcyclohexanedione).

One onium PGR used in crop production is chlormequat chloride (CCC), and the most widely used acylcyclohexanedione PGR is trinexapac-ethyl (TE; Palisade EC, Syngenta) (Rademacher, 2015). Prior to the development of TE, CCC was used commercially in perennial ryegrass seed crops in New Zealand, where it was observed to increase grass seed yields (Hampton, 1986). The greater seed yield response to TE in comparison to CCC eventually resulted in rapid grower adoption of TE.

Plant growth regulators containing CCC have not previously been registered for use in grass seed crops in Oregon, but a federal registration is pending in the U.S. (Adjust, Eastman Chemical Company). Early work by Hebblethwaite et al. (1978) examined the effect of CCC on perennial ryegrass and found that it had little effect on tiller length or lodging. However, seed yield was increased in some years, likely due to improved assimilate transfer to the seed. Hampton (1986) also evaluated effects of CCC on perennial ryegrass and found that neither tiller length nor lodging was reduced, but seed yield increases resulted from improved survival of tillers. Application of CCC alone had no effect on turf-type or forage-type tall fescue in Oregon, but a 31–35% increase in seed yield was observed with 210 g TE ha^{-1} + 750 g CCC ha^{-1} over the untreated control (Hudgins, unpublished). More recently, Szczepanek et al. (2021) showed an increase in seed yield from the use of CCC and TE + CCC in both strong creeping red and Chewings fescue with two nitrogen fertilizer rates over two production years.

The objective of this study was to determine the effects of CCC and combinations of CCC + TE on seed yield and yield components in turf-type perennial ryegrass seed crops grown under dryland conditions in western Oregon.

Materials and Methods

The field trial was established at OSU's Hyslop Crop Science Research Laboratory in the fall of 2019 with 'Fastball' perennial ryegrass. The first- and second-year seed harvests occurred in 2020 and 2021, respectively. Plot size was 11 feet x 45 feet. The experimental design for this trial was a randomized complete block with four replications.

Routine herbicide, molluscicide, and insecticide treatments were applied to manage pests as needed. Spring nitrogen was applied to plots at a rate of 140 lb N/acre. The PGR treatments were applied with a bicycle-type boom sprayer operated at 138 kPa with XR Tee Jet 8003VS flat spray nozzles.

The following PGR treatments were included:

- Untreated control (No PGR)
- 2.8 pt/acre Palisade (TE) at BBCH 32 (two nodes)
- 1.3 lb/acre Adjust (CCC) at BBCH 32
- 2.6 lb/acre Adjust at BBCH 32
- 3.9 lb/acre Adjust at BBCH 32
- 1.3 lb/acre Adjust + 2.8 pt/acre Palisade at BBCH 32
- 2.6 lb/acre Adjust + 2.8 pt/acre Palisade at BBCH 32
- 3.9 lb/acre Adjust + 2.8 pt/acre Palisade at BBCH 32
- 2.6 lb/acre Adjust at BBCH 32 + 1.3 lb/acre Adjust at BBCH 51 (head emergence)

At peak flowering (BBCH 65), three 0.1 m^{-2} samples were harvested (cut to 2 cm above ground level) at random from each plot to determine fertile tillers m^{-2}, tiller length cm^{-2}, and above-ground biomass. Samples were placed in a dryer at 65°C for approximately 48 hours and were then weighed to determine the above-ground biomass. Tillers were then counted, and length was determined by measuring ten stems randomly chosen from each sample.

Plots were swathed with a modified John Deere 2280 swather and combined with a Hege 180 plot combine. Subsamples of harvested seed were collected from each plot and cleaned using a Clipper M2B cleaner to determine cleanout percentage and clean seed yield. Seed weight was determined by counting two 1,000-seed samples with an electronic seed counter and weighing these samples on a laboratory balance. Harvest index (HI), the ratio of seed yield to above-ground biomass, was also quantified.

Results and Discussion

Results from the first year of the study (2020) indicate that 2.8 pt/acre Palisade was the only PGR treatment that affected seed yield (Table 1). This treatment increased seed yield by 15.9% over the untreated control. Treatments containing CCC, either alone or in a tank-mix, had no effect on seed yield.

Percent cleanout increased with all CCC + TE treatments, compared to the untreated control. Seed number and biomass were not affected by any of the PGR treatments. Seed weight decreased by 5.8 and 6.2% with the 1.3 lb/acre Adjust + 2.8 pt/acre Palisade and 2.6 lb/acre Adjust + 2.8 pt/acre Palisade treatments, respectively. There were no differences in fertile tiller numbers among any of the PGR treatments; however, all treatments containing TE reduced tiller height compared to the untreated control and all CCC-alone treatments. There was no effect on HI from any of the PGR treatments.

In the second year of the study (2021), all PGR treatments containing Palisade decreased seed yield, while treatments containing only CCC were not different than the untreated control (Table 2). The 2.8 pt/acre Palisade treatment decreased seed yield by 22.4%, while the Adjust + Palisade tank-mixes resulted in seed yield decreases ranging from 30.8 to 36.4%.

Percent cleanout increased with all treatments containing TE but was not different with treatments containing CCC alone. There were no differences in seed weight, biomass, or fertile tiller number among treatments. All CCC + TE tank-mix treatments decreased seed number and tiller height compared to

Table 1. Plant growth regulator (PGR) effects on first-year ‘Fastball’ perennial ryegrass, 2020.[1]

	Yield	Cleanout	Seed weight	Seed number	Biomass	Fertile tillers	Tiller height	Harvest index
	(lb/a^{-1})	(%)	(mg seed^{-1})	(no m^{-2})	(kg ha^{-1})	(no m^{-2})	(cm)	(%)
Untreated control	1,346 a	9.6 ab	1.529 cd	98,615	11,915	293	49.7 b	13.5
Palisade @ 2.8 pt/a	1,561 b	11.6 bcd	1.487 bc	117,693	8,616	237	31.9 a	20.3
Adjust @ 1.3 lb/a	1,346 a	10.6 abc	1.515 cd	99,570	9,676	252	48.0 b	15.9
Adjust @ 2.6 lb/a	1,385 a	10.7 abc	1.527 cd	101,763	8,923	231	47.9 b	18.2
Adjust @ 3.9 lb/a	1,328 a	10.8 abc	1.532 d	97,155	10,168	283	45.2 b	14.9
Adjust @ 1.3 lb/a + Palisade @ 2.8 pt/a	1,339 a	11.7 cd	1.455 ab	103,293	11,022	299	30.1 a	14.3
Adjust @ 2.6 lb/a + Palisade @ 2.8 pt/a	1,295 a	13.3 d	1.433 a	101,429	8,557	243	26.9 a	17.4
Adjust @ 3.9 lb/a + Palisade @ 2.8 pt/a	1,382 a	12.2 cd	1.488 bc	103,772	9,155	250	28.9 a	17.2
Adjust @ 2.6 lb/a + Adjust @ 1.3 lb/a	1,326 a	9.2 a	1.508 cd	98,635	10,538	266	48.2 b	14.6

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

Table 2. Plant growth regulator (PGR) effects on second-year 'Fastball' perennial ryegrass, 2021.[1]

	Yield	Cleanout	Seed weight	Seed number	Biomass	Fertile tillers	Tiller height	Harvest index
	(lb/a^{-1})	(%)	(mg seed^{-1})	(no m^{-2})	(kg ha^{-1})	(no m^{-2})	(cm)	(%)
Untreated control	652 c	14.5 a	1.224	59,611 cd	12,971	480	44.6 bc	5.7 de
Palisade @ 2.8 pt/a	506 ab	18.7 b	1.084	52,529 bc	14,381	471	39.3 b	4.0 abc
Adjust @ 1.3 lb/a	648 c	14.7 a	1.223	59,354 cd	14,354	501	44.0 bc	5.3 de
Adjust @ 2.6 lb/a	655 c	14.8 a	1.208	60,865 d	15,768	518	47.0 c	4.7 bcd
Adjust @ 3.9 lb/a	608 c	15.2 a	1.107	61,713 d	14,182	491	43.3 bc	4.9 cde
Adjust @ 1.3 lb/a + Palisade @ 2.8 pt/a	417 a	20.6 b	1.115	42,414 a	13,297	454	30.3 a	3.6 ab
Adjust @ 2.6 lb/a + Palisade @ 2.8 pt/a	415 a	21.6 b	1.078	43,709 a	13,308	434	29.0 a	3.5 a
Adjust @ 3.9 lb/a + Palisade @ 2.8 pt/a	451 a	20.4 b	1.068	47,067 ab	13,016	429	31.5 a	3.9 abc
Adjust @ 2.6 lb/a + Adjust @ 1.3 lb/a	600 bc	13.4 a	1.104	61,008 d	11,728	415	44.8 bc	5.8 e

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

the untreated control, TE alone, and CCC-alone PGR treatments. Harvest index was decreased with all PGR treatments containing TE.

The differences in seed yield response to PGR treatments between years can likely be attributed to differences in spring rainfall conditions. The long-term mean precipitation for March through June in the Willamette Valley is 10.34 inches. In 2020, the precipitation was slightly below the long-term mean at 9.17 inches. However, the precipitation during this same period in 2021 was only 5.17 inches. The dry conditions in 2021 resulted in lower seed yield, which likely was caused by lower seed weights and higher percent cleanout in the second-year stand.

The results of this study indicated that applications of CCC alone, or in a tank-mix with TE, should not be considered in western Oregon dryland perennial ryegrass seed crops at this time. However, more work is needed to evaluate CCC-containing PGRs on other varieties, under irrigation, and in other regions of Oregon where perennial ryegrass is grown in different environmental conditions. We recommend that TE continue to be used as an important management tool to increase seed yield in perennial ryegrass seed crops.

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EFFECTS OF THE PLANT GROWTH REGULATOR CHLORMEQUAT CHLORIDE ON FINE FESCUE SEED YIELD AND YIELD COMPONENTS

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Introduction

Several fine fescue grass seed crops (*Festuca rubra* L.) are produced in Oregon: strong creeping red fescue (*Festuca rubra* ssp. *rubra*), slender creeping red fescue (*Festuca rubra* ssp. *littoralis*), and Chewings fescue (*Festuca rubra* ssp. *commutata*). Fine fescues are used extensively as turf grasses and are valued for their broad adaptability to many climates, their slender leaves, and their low input requirements. In Oregon, fine fescues are grown in parts of northeastern Oregon and in the Silverton Hills of the Willamette Valley. Oregon production of Chewings and red fescue species was valued at approximately $27 million in 2020.

The benefits of the plant growth regulator (PGR) trinexapac-ethyl (TE; Palisade EC) in Oregon fine fescue seed production has been demonstrated since the early 2000s (Gingrich and Mellbye, 2001), and spring application of TE is now a standard practice.

In 2015, field research was initiated in Oregon to investigate the possible utility of another plant growth regulator, chlormequat chloride (CCC; Adjust), in grass seed crops, including fine fescue. As with TE, CCC acts on the gibberellin biosynthesis pathway, which reduces stem length. However, CCC acts at an earlier point in the pathway (Rademacher, 2015). Chlormequat chloride has been used successfully for decades in other grass-seed-producing regions of the world, but it has not been registered for use in grass seed crops in the United States. Across grass species, the most consistently successful use pattern for CCC has been in combination with TE. A federal registration is currently being sought for use in grass grown for seed, and, if registered, the new CCC product is anticipated to be available as a much more concentrated and affordable product relative to existing horticultural formulations.

Multiyear field trials looking at CCC in combination with TE in Chewings and creeping red fescue were conducted between 2018 and 2020 (Anderson et al., 2021). Results indicate that in first- and second-year Chewings fescue, seed yield increased significantly when TE + CCC was applied compared to TE alone or an untreated control. In creeping red fescue, no additional benefit over TE alone was observed. A study in Poland also found that CCC combined with TE increased average yields of Chewings and creeping red fescues by 9.3% (Szczepanek et al., 2021). Yield increases were attributed to both increased number of spikelets per panicle and reduced lodging. In related studies, CCC alone, or in combination with TE, reduced fertile tiller height in Chewings fescue, which was reportedly more responsive to plant growth regulators than creeping red fescue (Szczepanek et al., 2020).

To date, trial work with CCC in Oregon has been limited to lower rates, 1.3 lb a.i./acre or less, given the high cost and high application volumes of the currently available product (Cycocel, registered for use in ornamental nursery production). The main objectives of this study were the following:

- To further evaluate the efficacy of CCC in combination with TE to increase seed yield in Chewings fescue.
- To test whether higher rates of CCC in combination with TE provide an additional yield response in Chewings fescue.

Materials and Methods

This study was conducted on two established commercial Chewings fescue seed production fields located in the Silverton Hills. Both were planted in spring 2019, harvested in 2020, and open field burned following the first seed harvest in 2020. Work for this trial was conducted during the 2021 growing season, corresponding to the second year of seed harvest for each field. Site 1 was planted to variety 'Leeward', and Site 2 was planted to variety 'Momentum'. A randomized complete block design was utilized at each site with three replicates and individual plot sizes of 25 feet x 300 feet at Site 1 and 29 feet x 300 feet at Site 2. Each trial was fertilized in early spring by the grower at standard nitrogen rates, and a standard fungicide (Trivapro at 21 oz/acre) was applied at the time of PGR application.

Plant growth regulators were applied on April 22, 2021 using an ATV-mounted spray unit with a 29-foot boom calibrated to deliver 17.5 gpa. The growth stage at the time of PGR application corresponded to early stem elongation stage, or two-node stage (BBCH 32). The

OSU recommended rate of TE (1.4 pt/acre) was tested alone and in combination with three rates of CCC. Since this same TE rate was used in all treatments containing a PGR, we have simplified the names in the results and discussion text to TE or TE + CCC and the CCC rate. Treatments included the following PGR rates and combinations:

- Untreated control
- TE (TE 1.4 pt/acre)
- TE + CCC 1.3 (TE 1.4 pt/acre + CCC 1.3 lb/acre)
- TE + CCC 2.6 (TE 1.4 pt/acre + CCC 2.6 lb/acre)
- TE + CCC 3.9 (TE 1.4 pt/acre + CCC 3.9 lb/acre)

Above-ground biomass samples were collected June 7 during the period of peak flowering to end of flowering (BBCH 65–69) by taking three 1-ft^2 quadrat samples from random locations within each plot. Subsamples were then aggregated into a single composite sample from each plot and were analyzed for biomass and tiller height.

The middle of each plot was harvested with commercial equipment (swather and combine), equating to a harvest plot size of 14.5 feet x 300 feet and 16 feet x 300 feet at Site 1 and 2, respectively. Site 1 was swathed on June 29 and harvested on July 10, and Site 2 was swathed on July 6 and harvested on July 17. Dirt seed yield was determined with a weigh wagon. A subsample of harvested seed from each plot was cleaned to determine clean seed yield, percent cleanout, and seed weight (mg/seed). Harvest index (HI) was calculated as the seed yield relative to above-ground biomass for a given area, and number of seed per square meter was calculated from clean seed yield and seed weight.

Results and Discussion

Seed yield was higher than the untreated control when CCC, at all rates, was added to TE at Site 1, but yield showed no effect at Site 2 at any rate (Table 1). There was no effect of CCC rate on seed yield at either site. Application of TE alone did not affect seed yields at either site.

The addition of CCC reduced tiller height relative to untreated controls at both sites. At Site 1, TE + CCC 2.6 and TE + CCC 3.9 reduced tiller height relative to TE alone. At Site 2, all rates of CCC reduced tiller height relative to TE alone. Despite differences in tiller height, a significant reduction in above-ground biomass was not observed at either site. High variability was observed in above-ground biomass quadrat data, and this limited our ability to discern differences.

Harvest index (HI) is the ratio of seed yield to above-ground biomass. A higher HI means the crop had more seed production relative to above-ground biomass and can be thought of as indicating greater efficiency

Table 1. Effect of trinexapac-ethyl (TE) and chlormequat chloride (CCC) mixes on seed yield, cleanout, seed weight, seed number, above-ground biomass, tiller height, and harvest index of Chewings fine fescue.[1]

Treatment	Yield	Cleanout	Seed weight	Seed number	Biomass	Tiller height	Harvest index
	(lb/a)	(%)	(mg/seed)	(no/m^2)	(ton/a)	(cm)	(%)
Site 1							
Untreated control	1,683 a	7.5 a	0.9569 a	213,102	8.4	86.0 c	10.0 a
TE 1.4 pt/a	1,840 ab	6.7 ab	0.9693 ab	228,360	7.3	77.3 bc	12.9 ab
TE 1.4 pt/a + CCC 1.3 lb/a	1,985 b	6.4 ab	1.0056 b	236,443	6.9	66.5 ab	14.7 ab
TE 1.4 pt/a + CCC 2.6 lb/a	1,957 b	5.9 b	0.9964 ab	234,210	6.8	61.1 a	14.5 ab
TE 1.4 pt/a + CCC 3.9 lb/a	2,002 b	5.5 b	1.0059 a	236,525	6.7	63.3 a	15.2 b
Site 2							
Untreated control	1,795	9.3	0.9885	224,264	5.4	80.5 c	16.7
TE 1.4 pt/a	1,804	10.1	0.9952	225,878	5.4	69.1 b	16.7
TE 1.4 pt/a + CCC 1.3 lb/a	1,843	10.2	1.0014	229,135	5.0	56.2 a	18.3
TE 1.4 pt/a + CCC 2.6 lb/a	1,870	10.0	0.9957	233,687	4.9	56.5 a	19.5
TE 1.4 pt/a + CCC 3.9 lb/a	1,764	9.8	1.0027	218,346	5.4	56.2 a	16.7

[1] Data for each site were analyzed separately. Numbers followed by the same letter are not significantly different at LSD (*P* = 0.05). If no letters are present in a column, no significant differences were observed.

at allocating resources to seed production versus vegetative growth. At Site 1, only the highest CCC rate, TE + CCC 3.9, increased HI relative to the untreated control.

Seed weight was typical for Chewings fescue and ranged from 0.957 to 1.006 mg/seed across sites (Table 1). At Site 1, seed weight was higher with the TE + CCC 1.3 rate relative to the untreated control. This was not the case, however, for the higher CCC rate combinations, and no clear pattern emerged in seed weight. At Site 2, there was no effect of any PGR treatment on seed weight. Percent cleanout was not affected by PGRs at Site 2, but at Site 1 higher rates of CCC reduced cleanout relative to an untreated control. There was no effect of any PGR treatment on seed number.

Overall, the addition of CCC to the PGR mix was more effective at Site 1. At Site 2, we saw no effect of any PGR combination on yield or yield components, with the exception of tiller height, which was reduced by the application of TE and further reduced with the addition of CCC (Table 1). The lack of effects at Site 2 may relate to the variety and/or time of application relative to growth stage, or to minor environmental differences between the sites. Site 2 was at a slightly higher elevation, and, while both crops were at BBCH 32 at the time of PGR applications, Site 2 was on average about 1 week delayed in maturity relative to Site 1. Moisture stress and underlying differences in soil water content between the two sites also may have played a role. The spring of 2021 was the sixth driest spring since weather records began in 1889. Rainfall between March and June 2021 was less than half of normal for that time period, and it was exceptionally low in April and May.

We observed a small improvement in some yield components with a higher CCC rate, for example, lower tiller height, lower cleanout, and higher HI, but these did not translate to higher yields. To date, the data do not show an added benefit from higher CCC rates. However, in a year with less drought stress and higher biomass growth potential, the improved stem shortening observed at higher CCC rates could be beneficial in preventing lodging.

Overall, results show that the addition of CCC as a tank-mix partner with TE can increase yields relative to an untreated control in some cases, but results may be inconsistent due to weather, field location, or varietal response. It is not yet clear whether the additional benefit of CCC beyond TE alone will be consistent or large enough to provide a reliable return on investment. For example, at Site 1 the addition of CCC tended to increase yields by 140 lb/acre on average, compared to TE alone, but these differences were not statistically significant. No negative effects of TE alone or in combination with CCC were observed, despite extremely dry spring conditions.

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A STUDY OF ELECTROPHORESIS TESTING OF KENTUCKY 31 TALL FESCUE

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Introduction

The Federal Seed Act (FSA; 7 CFR §§ 201.1 to 201.78) requires that seed traded across state lines be labeled to accurately identify the species and variety. The United States Department of Agriculture Agricultural Marketing Service Seed Regulatory and Testing Division (SRTD) is responsible for FSA enforcement. State departments of agriculture may collect samples from seed lots suspected of being incorrectly labeled and submit them to SRTD for testing to evaluate germination, purity, and trueness to variety.

The SRTD determines the appropriate testing methods to verify trueness to variety (7 U.S.C. 1593). The traditional method used to evaluate trueness to variety is a grow-out test: the seed in question is planted, and the morphological characteristics of the resulting plants are compared to the characteristics established by the original breeder of that particular variety. Grow-out tests for tall fescue take several months because seed head characteristics are used to distinguish varieties.

Electrophoresis testing is an alternative molecular approach used to differentiate varieties of many crop species (Cooke, 1995). Proteins are extracted from plant tissue and forced through a gel medium that causes them to separate by size. The proteins create a pattern of bands in the gel, and differences in banding pattern can be used to differentiate among varieties. Testing protocols are crop-specific and target groups of proteins that are known to differ among varieties of that crop species. Electrophoresis methods are becoming increasingly common because results can be generated in weeks instead of months. Electrophoresis and grow-out tests are the only methods commonly used to differentiate among tall fescue varieties.

The SRTD has developed and adopted an electrophoresis test to differentiate between the tall fescue variety ‘Kentucky 31’ (K31) and other varieties (Wu and Payne, 2018). For the K31 electrophoresis test, proteins are extracted from the stem tissue of 4-week-old seedlings. Kentucky 31 produces a characteristic banding pattern. If a test sample produces a banding pattern that is not consistent with the expected K31 banding pattern, the SRTD determines that there is a “significant presence of a variety other than K31.” (The term “off-type” will be used here.)

In 2018, seed from a pair of Oregon commercial tall fescue seed production fields of K31 (treated as a single lot) was tested using electrophoresis and was determined to be off-type. However, a follow-up electrophoresis test was conducted on seed harvested from the same fields in 2020, and the test returned the opposite result, identifying the seed as K31. The seed used to plant the fields was purchased from a supplier of K31 seed stock, and seed from the source fields was tested and found to be K31 in 2019. This incident raised questions about the K31 electrophoresis test. Thus, this study was initiated to better understand how the conflicting electrophoresis test results came about.

Conflicting test results could occur if the test did not produce consistent results, or they could be a result of actual differences among samples. The repeatability of the electrophoresis test must be evaluated before it is possible to investigate differences among samples. Wind-blown pollen from a neighboring field of another variety might cause seed from part of a K31 field to test as off-type. This effect was expected to be most detectable as heterogeneity in the seed lot. Seed from multiple fields of the same variety are often combined in a single lot, so differences among fields could also result in one portion of a lot testing differently from another portion.

This project addressed two research questions:

1. Does the electrophoresis test produce consistent results for identical samples?

2. Is there heterogeneity in seed lots that leads to inconsistent electrophoresis test results?

Materials and Methods

Seed lots

Samples from nine tall fescue seed lots were included in this study (Table 1). These included five lots that were expected to be K31 and four lots of other varieties. The K31 lots included K31 seed stock, the 2020 lot that had

Table 1. Summary of tall fescue seed lots and number of samples submitted for electrophoresis testing.

		-- Round 1 --		-- Round 2 --	
Seed lot	Description	WL[1]	PL[2]	WL[1]	PL[2]
		----- (Number of samples) -----			
K31-1 2020	Seed harvested from this pair of fields produced conflicting test results (2018, 2020). Uncertified.	3	3	1	3
K31-2 2020	Uncertified seed harvested from a group of three	3	3	1	3
K31-2 2019	commercial fields in three crop years	3	—	1	—
K31-2 2018		3	—	1	—
K31-SS	MO-certified K31 seed stock, grown in Missouri	3	—	1	—
Honky Tonk II 2020	OR-certified turf-type tall fescue, field adjacent to K31-1	3	3	1	3
Fawn 2020	Uncertified forage type	3	3	1	3
Rustler 2019	Uncertified forage type	—	—	1	—
Brutus 2020	Uncertified forage type	—	—	1	—

[1] Samples that are representative of the whole lot. A single sample representative of the whole lot was collected, mixed, and split into replicate subsamples.

[2] Partial-lot samples collected from three individual pallets of each seed lot. Three samples were collected, and each was tested twice, once in each round of testing.

previous inconsistent test results (K31-1), and seed lots from the 2018–2020 crop years from another grower (K31-2). Other varieties included a turf-type ('Honky Tonk II') grown adjacent to K31-1 and three forage varieties: 'Fawn', 'Rustler', and 'Brutus'.

Experimental design

Two different approaches were used in this study to address the two research questions. The number of samples tested for each lot is shown in Table 1.

To address question #1, a representative sample was collected from each lot, mixed thoroughly, and split into replicate subsamples. This approach was designed to produce replicate subsamples that were as identical as possible. Four replicates were tested for each "whole-lot" (WL) sample: three replicate samples from each lot in the first round of tests, and one from each lot in the second round of tests (Table 1, see below for explanation of test rounds).

Sample collection to address question #2 was designed to capture heterogeneity within lots. Four lots (Table 1) were included in this portion of the study. Three partial lots, each consisting of a single pallet (50 or more 50-lb bags), were randomly selected from each lot, and a representative sample was collected from each pallet. These samples are referred to as partial-lot samples (PL). If there is heterogeneity in the lot, PL samples from that lot have the potential to differ from one other. Each PL sample was mixed thoroughly and split to form replicates. A total of six tests from each lot were completed: three potentially unique PL samples, each tested in the first round of testing and again in the second round of testing (two replicates).

The seed lots Rustler 2019 and Brutus 2020 were added at a later stage of the project to increase the number of non-K31 varieties tested. A single representative sample was collected from each lot and tested once. Partial-lot samples were not collected from these lots.

Sample collection and submission

Seed samples were collected by an Oregon Department of Agriculture seed regulatory specialist in February 2021, except for the Rustler 2019 and Brutus 2020 samples, which were collected in June 2021. Seed lots K31-2 2018 and K31-2 2019 were sampled at the time of cleaning by an in-process auto-sampler in 2018 and 2019, respectively. The grower saved seed samples (one 1-gal bag each), and a representative portion of these samples was collected by the seed regulatory specialist for this study. The K31-2 2018 and K31-2 2019 samples are considered WL samples because they are representative of the whole lot. All other samples were collected using the standard AASCO sampling protocol (Guerke, 2006). All samples were collected once, and a portion of each sample was retained for future testing.

Samples were submitted to the SRTD for K31 electrophoresis testing by the ODA on two separate dates. A second round of testing was done because identifying information had been included with the first sample submission, so the samples were not blind. All potentially unique samples were submitted for testing in the second round, as well as two samples from lots that were not included in the first round (Table 1). The second batch of samples was blind; only randomly generated sample numbers were used to identify samples.

Results and Discussion

The results from SRTD included images of gel banding patterns in addition to the determination of whether each sample was K31 or off-type. Each gel included a K31 control sample. Four bands are used to distinguish K31 from other varieties, and these bands were noted on the control sample with labels "a" through "d." Figure 1 shows one of the gels from the second round of tests.

The SRTD had information about the identities of the samples in the first batch of tests, which could bias the results. However, we have several reasons to believe that the first round of testing was valid and worth including here. Samples submitted to the SRTD as part of routine regulatory activities are provided with all label information and are collected from lots that are believed to have inaccurate labeling. Therefore, as a matter of course, all samples submitted to SRTD are not submitted blindly, and SRTD considers the label information to be potentially inaccurate.

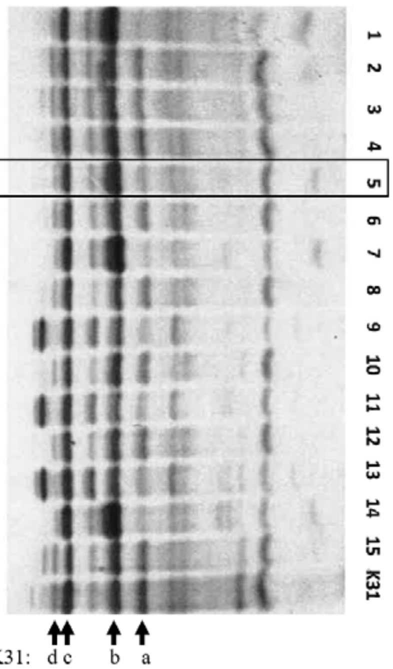
Knowledge of sample identity could not alter the banding pattern produced by the sample, but it could affect how a human interprets that banding pattern. Since images of the gels were provided by the lab we were able to independently interpret the gels (without knowing sample identities) and compare our interpretation to that of the lab. Comparisons of round one (not-blind) and round two (blind) test results from the same lots confirmed that the gel banding patterns were the same. There were no discrepancies between the results obtained in the first and second batches of tests.

In regards to question #1, all replicate WL samples collected from the same lot returned the same test result and showed the same banding pattern. These results include seven lots replicated four times each. Additionally, 2 replicate tests were conducted for each PL sample, for another 12 pairs of replicate tests. These results show that the K31 electrophoresis test returns repeatable results when identical samples are tested.

In regards to question #2, no evidence of heterogeneity was detected in this study. Three PL samples were tested each for four lots. All PL samples from the same parent lot returned the same result and banding pattern. Although heterogeneity was not detected, this study tested only four lots. More research would be needed to rule out the possibility of heterogeneity as a cause of inconsistent test results.

All samples that were believed to be K31 (K31-1, K31-2, and K31-SS) produced a banding pattern that matched that of the laboratory check samples and were determined to be K31 by SRTD. Samples from other varieties produced different distinctive banding patterns. For example, the turf-type variety 'Honky Tonk II'

Seed lot	Sample type	Test result
Fawn 2020	PL	Off type
K31-1 2020	PL	K31
K31-2 2020	PL	K31
K31-1 2020	PL	K31
Rustler 2019	WL	K31
K31-1 2020	PL	K31
Fawn 2020	PL	Off type
K31-2 2020	PL	K31
Honky Tonk II 2020	PL	Off type
K31-2 2020	PL	K31
Honky Tonk II 2020	PL	Off type
K-31 SS	WL	K31
Honky Tonk II 2020	PL	Off type
Fawn 2020	PL	Off type
K-31 1 2020	WL	K31
Laboratory K31 Check		-



Characteristic bands used to identify K31: d c b a

Figure 1. Image of electrophoresis test results from the second round of testing annotated with seed lot, sample collection method (WL = whole-lot replicate; PL = partial-lot), and the test result determined by the SRTD laboratory. A box highlights the sample that was incorrectly determined to be K31 by the testing laboratory. The gel is shown sideways to make text easier to read.

showed evenly spaced dark bands (Figure 2). Combining replicate and PL samples, four seed lots were tested ten times each, and three seed lots were tested four times each. All tests of the same lot produced the same banding pattern and test result.

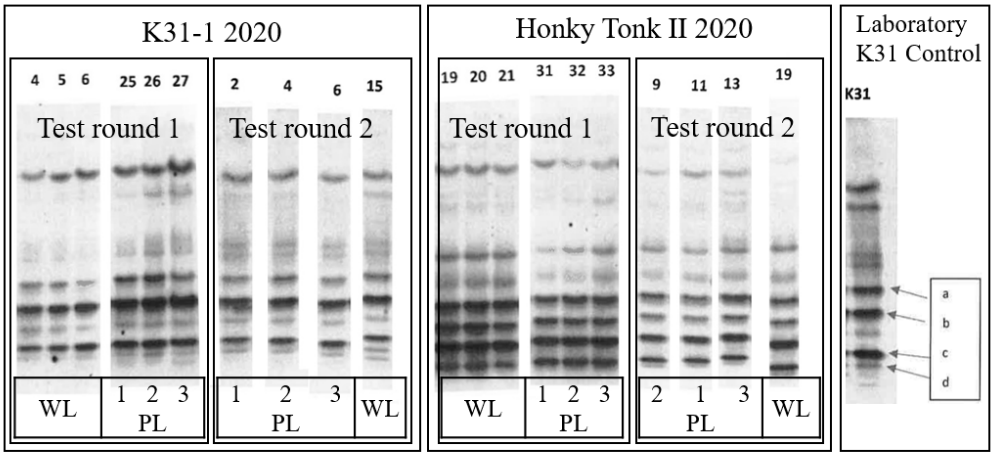


Figure 2. Electrophoresis test results for the lots K31-1 2020 and Honky Tonk II 2020 in test rounds 1 and 2. Samples are identified as whole-lot (WL) or partial-lot (PL). PL samples with the same number and variety are replicates of the same sublot.

Of the 54 samples submitted for testing, 1 sample was incorrectly identified. This sample was a non-K31 forage type (seed lot Rustler 2019), but the test results identified it as being K31 (a false positive). Unlike the other seed lots, which were tested in both rounds, only a single sample each of Rustler 2019 and Brutus 2020 was included in the second (blind) round of testing.

The banding pattern of the Rustler 2019 sample (Figure 1, row 5) has a faint “a” band and a dark “b” band compared to the K31 check sample. The Rustler 2019 banding pattern shows some similarities to the banding pattern of Fawn 2020 samples (Figure 1, rows 7 and 14). The determination by SRTD for this sample should be considered in context: The electrophoresis test is used on samples that are labeled as K31 but suspected of being mislabeled (a violation of the FSA). It would be reasonable to consider the banding pattern of the Rustler 2019 sample to be insufficiently different from the K31 banding pattern to determine that it was not K31.

These results indicate that the K31 electrophoresis test can produce consistently repeatable results, producing similar banding patterns. One false positive result was obtained when a forage-type tall fescue lot was incorrectly determined to be K31, likely due to human interpretation of the banding pattern.

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Acknowledgments

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SLUG PESTS OF GRASS AND FORAGE SEED PRODUCTION SYSTEMS IN OREGON

R.J. Mc Donnell

Introduction

Slugs are among the most important pests of grass and forage seed production in Oregon and have been estimated to cause $60 million in damage to these crops annually (Salisbury, 2015). Although the gray field slug is the most damaging species, there are a number of other pest slugs that are largely overlooked or misidentified. Although multiple pest slug species can co-occur in the same field, one species often dominates.

Accurate identification of pest slug species is essential for successful management, as some control strategies work better with certain slug species than with others. For example, field slugs (*Deroceras* spp.) are more susceptible to metaldehyde baits than are roundback slugs (*Arion* spp.) (Wedgewood and Bailey, 1988). In fact, many of the overlooked pest slugs in seed crops in Oregon are *Arion* species. Because current control measures in the Willamette Valley focus heavily on the use of molluscicidal baits, the importance of accurately identifying the pest species infesting a crop cannot be overstated. The goal of this report is to give an overview of the main slug pests of grass and forage seed crops and to provide an easy-to-use field identification key.

Basic Slug Morphology

A basic knowledge of the main body parts of slugs is required for accurate identification (Figure 1). Key features include the mantle, which is a saddle-shaped structure located behind the head. The position of the breathing pore on the mantle is an important diagnostic characteristic. This pore is typically either located in the posterior (closer to the tail) or the anterior (closer to the head) part of the mantle (Figure 1).

The foot fringe is where the body meets the foot. There are two pairs of tentacles located at the anterior (head) end of the body, the upper ocular tentacles, which have eye spots, and the lower peduncular tentacles. Mucus is produced by both the body and the foot, and its color and consistency (watery or sticky) can be important for distinguishing different species.

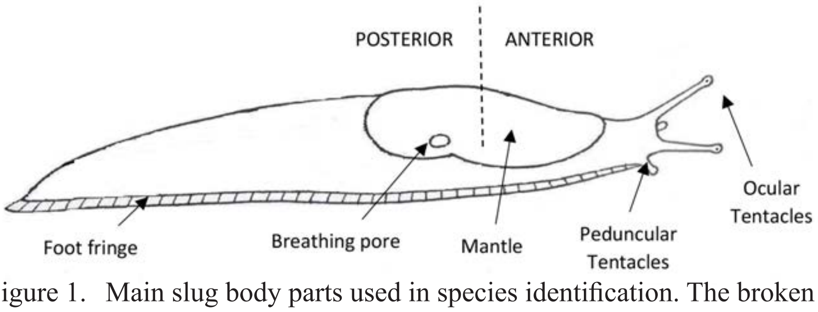

Figure 1. Main slug body parts used in species identification. The broken line illustrates the approximate midpoint of the mantle. If the breathing pore is to the left of this line (toward the tail), it is termed posterior; if it is to the right (toward the head), it is termed anterior. In this figure, the breathing pore is in the posterior part of the mantle.

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Field Identification Key

1. Breathing pore located posterior to the midpoint of the mantle (as in Figure 1)........ *go to 2*
   Breathing pore located anterior to or at the midpoint of the mantle........ *go to 3*

2. Slug brown; body mucus watery and colorless........ **Marsh slug**
   Slug cream or gray, often with darker flecks; body mucus sticky,
   becoming milky colored when slug is handled........ **Gray field slug**

3. Foot fringe with thin, vertical lines ....**Dusky slug**
   Foot fringe without thin, vertical lines .... *go to 4*

4. Grayish-white slug; foot mucus colorless........ **White-soled slug**
   Yellowish-brown slug; foot mucus yellow or orange .... **Hedgehog slug**

To view photographs of these slug species, visit the OSU Slug Portal website at https://agsci.oregonstate.edu/slug-portal.

Brief Species Descriptions

Gray field slug (*Deroceras reticulatum*)
A small to medium-sized slug, up to 2 inches (50 mm) long when extended. Specimens in the Willamette Valley tend to be gray or cream colored, with dark flecking throughout the body. Easily identified because its mucus typically changes from colorless to milky when it is handled. The most abundant and damaging slug species in grass and forage seed crops in Oregon. Unlike some pest slugs (e.g., the dusky slug), this species often is dispersed throughout crop fields (Rowson et al., 2014).

Marsh slug (*Deroceras laeve*)
A small, fast-moving slug, up to 1 inch (25 mm) in length when extended. Mucus is clear and watery. In the Willamette Valley, specimens tend to be pale chestnut to deep brown in color. The marsh slug is amphibious and can survive flooding events that kill other slug species. It may intentionally enter the water and survive for days completely submerged. Eggs also hatch under water (Welter-Schultes, 2012). Given this behavior, this species likely thrives in the wetter parts of grass and forage seed production fields.

Dusky slug (*Arion subfuscus*)
A medium-sized slug, up to 2.75 inches (70 mm) long when crawling and typically brownish yellow in color. Body mucus is yellow or orange. The foot fringe has thin, black, vertical lines. The dusky slug lives primarily at the edge of fields, and it has a preference for dense vegetation. However, it has been observed moving into crops, where it likely facilitates fertilization of the fungus *Epichloë typhina*, which causes choke disease in orchardgrass (Hoffman and Rao, 2013).

White-soled slug (*Arion circumscriptus*)
Also known as the brown-banded slug, this small to medium-sized species is up to 1.5 inches (40 mm) long when extended. The body tends to be grayish white, mucus is colorless, and the sole of the foot is white or light gray. Over the past 15 years, this slug has become more common in Oregon. Based on collections, it is the second most abundant slug species in grass and forage seed crops and is more prevalent in the northern part of the Willamette Valley. Like the gray field slug, it often is found dispersed throughout the field.

Hedgehog slug (*Arion intermedius*)
A small slug, up to 0.75 inch (20 mm) in length when crawling. Sole mucus is yellow to orange. Body color varies, but specimens in the Willamette Valley tend to be gray or brownish yellow. Although not visible to the naked eye, the prickles on this slug’s body when at rest gives it its name. This species has only recently been found associated with grass and forage seed fields, and it seems to be confined to field edges.

EFFICACY OF APHID CONTROL OPTIONS IN RED CLOVER GROWN FOR SEED

D.M. Lightle, M.A. Mattsson, and B.C. Donovan

Introduction

Clover aphid (*Nearctaphis bakeri*) and pea aphid (*Acyrthosiphon pisum*) are small aphids that attack red clover. In red clover, aphids require annual control to prevent seed yield reduction and harvest issues resulting from the sticky honeydew produced by aphid feeding. Clover seed growers typically treat for aphids in mid-June, just prior to clover bloom (Anderson, 2021).

Chlorpyrifos is widely used by growers because it has a long residual period; an application just prior to bloom provides aphid control through the majority of the clover bloom period. This eliminates the need for a second application while honeybees are foraging. Clover seed producers identified aphids as a primary target for chlorpyrifos applications in two grower surveys conducted in 2021.

The Oregon Department of Agriculture finalized new rules in 2020 to phase out chlorpyrifos use in agricultural production by December 31, 2023 (ODA, 2020). The objective of these trials was to identify potential alternatives to chlorpyrifos for aphid control in red clover seed production.

Materials and Methods

Aphid control was evaluated at two commercial red clover seed production fields in Washington County, Oregon. The plot size at each site was 13 feet x 30 feet. Insecticide treatments (Table 1) were applied in a randomized complete block design with four replicates. Treatments were applied with a four-nozzle boom sprayer pressurized with CO_2 and calibrated to deliver 20 gal/acre through TeeJet XR11002VS nozzles at 30 psi. Applications at Site A were made on June 25, 2020, and applications at Site B were made on July 2, 2020.

Table 1. Insecticide treatments, trade names, and rates applied at each field site, 2020.

Active ingredient	Trade name	Rate
		(amt product/a)
Flonicamid	Beleaf 50 SG	2.8 oz
Bifenthrin	Brigade 2 EC	6.4 fl oz
Cyantraniliprole	Exirel	18.0 fl oz
Chlorpyrifos	Lorsban Advanced	16.0 fl oz
Afidopyripen	Sefina	6.0 fl oz
Afidopyripen	Sefina	3.0 fl oz
Flupyradifurone	Sivanto Prime 200 SL	10.5 fl oz
Sulfoxaflor	Transform 50 WG	1.5 oz
Untreated control	—	2.8 oz

Efficacy was determined by sampling 12 clover flowers per plot at 9, 13, 20, and 27 days after treatment (DAT) (Site A) or at 7, 14, 21, and 30 days after treatment (Site B). Samples were frozen until processed. Each clover flower was examined under a dissecting microscope, and the aphids present were counted. No differentiation was made between the two common species of aphids found. Data were $\log_{10}(X+1)$ transformed to meet model assumptions, analyzed with ANOVA, and means separated according to Fisher's Least Significant Difference (LSD) at $P = 0.05$.

Results and Discussion

Results, Site A (Table 2)

- No treatments were different from the untreated check on any of the sampling dates.
- At 9 DAT, Exirel had greater numbers of aphids than Beleaf, Brigade, Lorsban Advanced, Sefina (6 fl oz), and Transform treatments.
- At 27 DAT, Exirel had greater numbers of aphids than Sefina (3 fl oz) and Transform treatments.
- No phytotoxicity was observed with any of the insecticide treatments.

Results, Site B (Table 3)

- At 7 DAT, Lorsban and Sivanto performed better than Brigade, Exirel, Sefina (6 fl oz), and the untreated control.
- At 14 DAT, Brigade performed better than Exirel, and no treatments were different from the untreated check.
- At 21 DAT, both Sivanto and Transform had fewer aphids than the untreated check. Exirel had more aphids than Beleaf, Brigade, Sefina (both rates), Sivanto, and Transform.

- At 30 DAT, Brigade, Sefina (both rates), Sivanto, and Transform all had fewer aphids than the untreated check, Exirel, and Lorsban.
- No phytotoxicity was observed with any of the insecticide treatments.

Discussion

As is frequently the case in small-plot trials, variation in insect pressure among replications can sometimes obscure treatment effects, leading to what was observed at Site A—large numerical differences in means between treatments (e.g., the untreated control and Transform treatments at 27 DAT) but no statistical differences. Nonetheless, several patterns hold true across both sites:

- Exirel did not provide control of aphids and, in fact, seemed to exacerbate insect pressure. This led to numerically, but not statistically, higher insect counts in Exirel-treated plots than in untreated control plots in both trials.
- Several materials provided long-lasting reduction in aphid numbers (residual control) for as long

Table 2. Site A: average aphid counts (adults and nymphs) per 12 flowers at each sample timing.[1]

Treatment	Rate	Aphids (adults + nymphs) (average per 12 flowers)[2]			
	(amt. product/a)	9 DAT	13 DAT	20 DAT	27 DAT
Beleaf 50 SG	2.8 oz	0.50 b	5.75	30.75	80.25 ab
Brigade 2 EC	6.4 fl oz	0.50 b	17.00	13.00	59.50 ab
Exirel	18.0 fl oz	14.00 a	8.50	61.25	224.25 a
Lorsban Advanced	16.0 fl oz	0.25 b	2.00	22.50	104.50 ab
Sefina	6.0 fl oz	0.25 b	4.75	7.25	35.00 ab
Sefina	3.0 fl oz	1.50 ab	1.25	13.00	17.50 b
Sivanto Prime 200 SL	10.5 fl oz	0.75 ab	3.25	11.00	58.50 ab
Transform 50 WG	1.5 oz	0.25 b	1.50	10.50	20.75 b
Untreated control	2.8 oz	6.25 ab	19.00	32.25	140.25 ab
$P > F$		< 0.01	0.7	0.3	0.02

[1] Means within columns followed by a common letter are not significantly different ($P \le 0.05$, Fisher's LSD).

[2] Log_{10} (X+1) transformed data used for ANOVA analysis; nontransformed means shown in table.

Table 3. Site B: average aphid counts (adults and nymphs) per 12 flowers at each sample timing.[1]

Treatment	Rate	Aphids (adults + nymphs) (average per 12 flowers)[2]			
	(amt. product/a)	7 DAT	14 DAT	21 DAT	30 DAT
Beleaf 50 SG	2.8 oz	5.00 ab	13.50 ab	42.50 bc	74.75 ab
Brigade 2 EC	6.4 fl oz	10.00 a	3.50 b	16.75 bc	17.50 c
Exirel	18.0 fl oz	18.00 a	51.50 a	159.75 a	192.50 a
Lorsban Advanced	16.0 fl oz	2.00 b	29.75 ab	69.50 ab	89.50 a
Sefina	6.0 fl oz	11.00 a	11.00 ab	16.75 bc	18.25 c
Sefina	3.0 fl oz	13.75 ab	20.25 ab	18.25 bc	22.00 bc
Sivanto Prime 200 SL	10.5 fl oz	1.00 b	2.50 ab	12.75 c	14.25 c
Transform 50 WG	1.5 oz	1.75 ab	7.75 ab	15.25 c	17.00 c
Untreated control	2.8 oz	21.25 a	25.25 ab	61.50 ab	83.00 a
$P > F$		< 0.001	0.03	< 0.001	< 0.001

[1] Means within columns followed by a common letter are not significantly different ($P \le 0.05$, Fisher's LSD).

[2] Log_{10} (X+1) transformed data used for ANOVA analysis; nontransformed means shown in table.

as 30 DAT, including Sefina, Sivanto Prime, and Transform. Sefina and Sivanto Prime have labels for aphid control in clover seed production. Because of regulatory hurdles, a label for Transform is not being pursued at this time.

- Brigade (bifenthrin) also performed well over the duration of the trials. Although it could be a direct substitute for chlorpyrifos because of its broad-spectrum activity and relatively low cost, it poses a greater threat to pollinators than other better-performing materials in these trials (i.e., Sefina and Sivanto Prime). The pollinator risk makes Brigade less attractive than alternatives.

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PROSPECTS FOR WIREWORM MANAGEMENT IN GRASS SEED PRODUCTION SYSTEMS

L.G. Van Slambrook, N. Kaur, B.C. Donovan, and N.P. Anderson

Introduction

Wireworms, the long-lived (approximately 2–5 years) larval stage of click beetles, are economically important crop pests that cause damage to germinating seeds and seedlings of numerous vegetable and field crops worldwide (Vernon and van Herk, 2013). This damage results in stunted plant growth, poor stand establishment, and yield loss. Adults feed only on flowers and pollen and therefore do not cause substantial damage to crops.

Adults are one-third to one-half inch long, slender, brown to black beetles. When placed on their backs, they will “spring” into the air with a distinct clicking action to right themselves. Adult wireworms usually emerge, mate, and lay eggs from late spring through summer, depending on the species. Small, white eggs are laid in clutches in the soil. Many species are attracted to grasses to lay eggs.

Larvae are one-quarter to 1 inch long, slender, segmented, yellow-brown-bodied insects with a dark head capsule and three pairs of small legs behind the head. The last segment of the body is usually pronged, forked, or “keyhole-shaped” at the end. Wireworm species identification is extremely difficult. The shape of the tail with appendage designs on the end can help distinguish among genera (Dreves et al., 2021).

Common wireworm genera that are encountered in cereals and other host crops of western Oregon include a complex of *Limonius* species (*Limonius canus*, the Pacific Coast wireworm; *Limonius californicus*, the sugar beet wireworm; and *Limonius infuscatus*, the western field wireworm). In eastern Oregon, *Ctenicera* species (Great Basin wireworms) occur, in addition to *Limonius* species. Several invasive species from Europe (such as *Agriotes obscurus* and *A. lineatus*) have also been reported in Washington, Oregon (Andrews et al., 2008), and the Fraser Valley of British Columbia in small fruit, vegetable, ornamental, and forage cropping systems.

Over the past 4 decades, wireworm damage has been effectively and inexpensively managed by the first generation of highly toxic and persistent preplant insecticides, such as organochlorines and organophosphates, which are applied to soil and seeds. Due to phasing out of some of these key insecticide groups, wireworms are reemerging as a problematic pest in the Pacific Northwest region of the United States. Better understanding of basic wireworm biology and ecology, the species complex present in cool-season grasses grown for seed, and efficacy of novel insecticide groups is required to develop alternative management strategies for Oregon grass seed crops.

A new insecticide containing the active ingredient broflanilide (Teraxxa) was recently registered by BASF as a seed treatment for the control of wireworms in wheat and other small grain crops. Broflanilide represents a new mode of action (Group 30) and belongs to a class of insecticides known as “meta-diamides” (Nakao and Banba, 2016). Another new insecticide with the active ingredient chlorantraniliprole (Group 28), trade name Vantacor, was recently registered for use in grass grown for seed.

Field efficacy data for wireworm control in Oregon grass seed crops are needed for establishing use patterns for the registered products and to support future registration of promising chemistries. The objectives of this study were as follows:

- To determine the time of year when wireworms cause damage to grass seed.
- To determine the effectiveness of the new insecticides broflanilide (Teraxxa) and chlorantraniliprole (Vantacor) against wireworms in grass seed crops.

Materials and Methods

2021 monitoring efforts

Adult trapping efforts consisted of using proprietary pitfall traps, Vernon Pitfall Traps (VPTs), which deploy an aggregation or pheromone lure specific to the targeted species (*Limonius* spp., *A. obscurus*, and *A. lineatus*). These traps were deployed in grass seed crops at one commercial fine fescue field in Marion County, one research plot of perennial ryegrass at OSU’s Hyslop Research Farm, and one research plot with both tall fescue and fine fescue at OSU’s Vegetable Farm. At each site, two VPTs per species were installed, totaling six traps per site placed at least 18 feet apart.

Traps were checked weekly from May through June 2021. Insect counts were made, and identification to the species level was confirmed in the laboratory.

For larval sampling, five commercial grass seed fields (both tall fescue and perennial ryegrass) in Benton, Polk, and Marion counties were selected based on historic wireworm infestations as reported by growers and crop consultants. A commonly used baiting technique for larval sampling in cereal crop systems was used in the fall of 2021 (Morales-Rodriguez et al., 2017). This method entailed burying a small nylon stocking filled with wheat and barley seed (bait bags) that had been soaked in water for 24 hours to imbibe the seeds and initiate germination. After bait bags were buried in the soil, the seeds released CO_2 to attract nearby wireworms. We prepared five stocking baits per site and buried them in random locations within each field. The bait traps were checked on a weekly basis to identify a field site with reliable wireworm pressure sufficient for conducting an insecticide efficacy trial.

Field efficacy trial

Selected foliar insecticide treatments for wireworm control were evaluated. This experiment was performed in a commercial tall fescue seed field in Polk County. The field was planted in spring 2021 with the cultivar ‘Sunset Gold’ at a seeding rate of 8 lb/acre with a 12-inch row spacing. Seeding depth was approximately 0.75 inch. The experimental plots were 30 feet long x 10 feet wide, with a 5-foot buffer separating each plot. The experimental design was a randomized complete block with four replications.

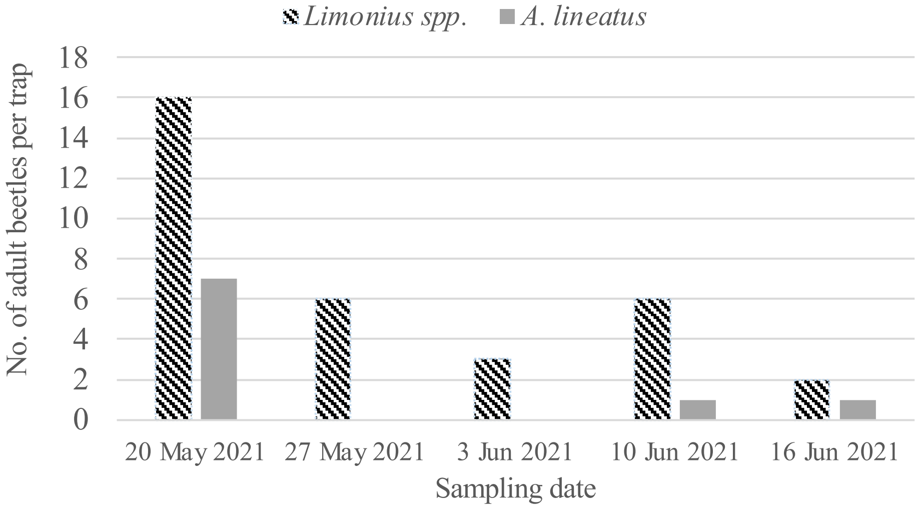

Figure 1. Species composition of wireworm species (*Limonius* spp. and *Agriotes lineatus*) detected during the 2021 monitoring period in a commercial fine fescue field in Marion County, OR.

Insecticide treatments included:

- Vantacor (2.5 fl oz/acre)
- Lorsban (24 fl oz/acre)
- An experimental broflanilide product, BAS4007I (1.14 fl oz/acre and 2.27 fl oz/acre)

Control plots were not treated with any insecticides.

Treatments were applied on October 12, 2021, using a CO_2-pressurized backpack sprayer (Bellspray Inc., Opelousas, LA) at a spray volume of 20 gal/acre at 24 psi through AM 11002 nozzles. Insect counts for wireworm larvae were taken posttreatment by deploying bait bags containing germinating wheat and barley seed (as previously described) at the center of each plot. Data were collected at 3, 7, and 28 days after treatment (DAT). Data were analyzed by ANOVA, and means were separated using Fisher’s protected LSD ($P \leq 0.05$).

Results and Discussion

Monitoring

No wireworms were detected in the traps deployed in perennial ryegrass at OSU’s Hyslop Farm during the monitoring period from May through June 2021. A total of ten *Limonius* spp. adults were captured at the OSU Vegetable Farm in both tall and fine fescue during the 2021 monitoring period, but there was no detection of *A. obscurus* or *A. lineatus* at this site.

Adults of both *Limonius* spp. (33 total) and *A. lineatus* (9 total) were trapped in the commercial fine fescue field site during 2021 monitoring efforts (Figure 1). This is the first report of *A. lineatus* in a commercial grass seed field in western Oregon, indicating the westward movement of yet another important invasive pest species.

Efficacy results

Bait trapping efforts during fall 2021 resulted in the identification of a field site with reliable pest pressure (up to six larvae per bait station) to conduct an insecticide efficacy trial. At 3 DAT, the untreated control and Vantacor treatments had an average of 5.5 wireworms per bait station (Table 1). Treatment means for Lorsban (average of 2.2 wireworms per bait station) and BAS4007I (average of 4 and 4.5 wireworms at low and higher application rates, respectively) were statistically different from the untreated control.

At 7 DAT, Vantacor had an average of 1.7 wireworms per bait station, followed by the untreated control (an average of one wireworm per bait station), Lorsban (an average of one wireworm per bait station), and BAS4007I (an average of 0.7 and 0.5 wireworms at low and higher application rates, respectively). At 28 DAT, there was an overall decline in wireworm captures in all treatments.

There were no differences among the insecticide treatments (mean wireworm larvae per bait station per treatment) at 3, 7, or 28 DAT. No phytotoxicity or differences in plant vigor were observed with any insecticide treatment. This trial will be repeated in fall 2022 to validate the efficacy data.

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Table 1. Trade names, active ingredients (class), rate, and mean number of wireworms per bait station per sampling date.

			Wireworms/bait station		
Trade name	Active ingredient (insecticide class)	Rate	---------------- (mean no.) ----------------		
			3 DAT	7 DAT	28 DAT
Untreated control	—	—	5.5	1.0	0.7
Vantacor	Chlorantraniliprole (Group 28)	2.50 fl oz/acre	5.5	1.7	0.2
Lorsban	Chlorpyrifos (Group 1B)	24.00 fl oz/acre	2.2	1.0	0.0
BAS4007I	Broflanilide (Group 30)	1.14 fl oz/acre	4.0	0.7	0.5
BAS4007I	Broflanilide (Group 30)	2.27 fl oz/acre	4.5	0.5	0.0
P-value			0.5966	0.6419	0.4473

SULFOSULFURON FOR ROUGHSTALK BLUEGRASS CONTROL IN SEEDLING KENTUCKY BLUEGRASS SEED CROPS

J.F. Spring, R.P. Affeldt, and D.L. Walenta

Introduction

Kentucky bluegrass (*Poa pratensis* L.; KBG) and roughstalk bluegrass (*Poa trivialis* L.) have both been successful seed crops in central Oregon for decades, despite the fact that most KBG markets tolerate little or no seed contamination from roughstalk bluegrass. While volunteer roughstalk bluegrass is a common weed in seedling KBG in central Oregon, it has been successfully controlled with the ALS-inhibitor (Group 2) herbicide primisulfuron, formulated as Beacon and as a premix with dicamba as NorthStar.

Production of primisulfuron was discontinued by the primary registrant Syngenta in 2018, and it has been unavailable in the retail chain since then. Despite acquisition of the active ingredient by Gowan Company in late 2020, manufacture of primisulfuron has not yet resumed, and it is unclear if or when this might occur. Best predictions available at the time of writing are that primisulfuron will remain out of production and unavailable for at least 3–5 years. Production and regulatory concerns (specifically, the need to generate required federal feeding tolerances for primisulfuron to allow reregistration in KBG) both contribute to this anticipated delay.

On the basis of previous work done in central Oregon (Jeliazkova et al., 2020; Spring and Affeldt, 2021) and trials conducted in 2021 (described below), the ALS-inhibitor herbicide sulfosulfuron (Outrider, Valent USA) recently received 24c Special Local Needs registration for use in seedling and established KBG in Oregon (SLN No. OR-220002).

In the 2021 crop year, field trials were established in newly seeded irrigated KBG stands in Jefferson and Union counties (Madras and La Grande, respectively) with the following goals:

- To complement results of previous trials in central Oregon.
- To evaluate Outrider activity on witchgrass and green foxtail in spring-planted KBG in northeast Oregon.
- To continue data generation in support of the recently approved 24c SLN registration for KBG in Oregon.

Materials and Methods

Field trials were established in Jefferson County (Madras area) in five newly planted commercial stands of KBG established with typical production practices in August 2020. Only two of these trials were completed through seed yield (due to inadvertent overspray by the grower, winter stand loss to cattle damage, or severe volunteer wheat competition, depending on the site).

Trials were arranged in a randomized complete block design with four replicates and individual plot size of 10 feet x 30 feet. Site 1 was a stand of ‘Wildhorse’ in a furrow-irrigated loam soil, and Site 2 was a stand of ‘Rockstar’ in a loam soil under center pivot irrigation.

Beacon and Outrider were applied at several rates and timings (Figure 1):

- In the fall only (Outrider at 0.38, 0.5, and 0.76 oz/acre)
- Split-applied in both fall and spring (Beacon at 0.38 oz/acre followed by 0.38 oz/acre
- Split-applied in both fall and spring (Outrider at 0.38 oz/acre followed by 0.25 or 0.38 oz/acre)

Applications were made with a CO_2-powered backpack sprayer calibrated to deliver 15 gal/acre using coarse droplet size. All treatments included MSO at 1% v/v and liquid AMS at the equivalent of 8.5 lb AMS/100 gal. Fall herbicide applications were made in late October to early November when KBG was at the two- to four-tiller stage. Roughstalk bluegrass was present only at Site 1 and had three to six tillers at the time of application. Spring applications were made in mid-April, after the first irrigation of the season.

Crop injury was rated in late April and again in June (at KBG heading) on a scale from 0 to 100%, with no effect at 0 and complete plant death at 100%. In June, accurate delineation of individual roughstalk bluegrass plants from within the dense KBG sward was not possible, so weed control was rated on a 0 to 3 categorical scale, with 0 indicating absence from an individual 10-foot x 30-foot plot, 1 and 2 representing one or two individual headed roughstalk bluegrass plants within an individual plot, and 3 representing three or more headed individuals. Severely suppressed plants that had not produced seed heads were excluded from evaluation.

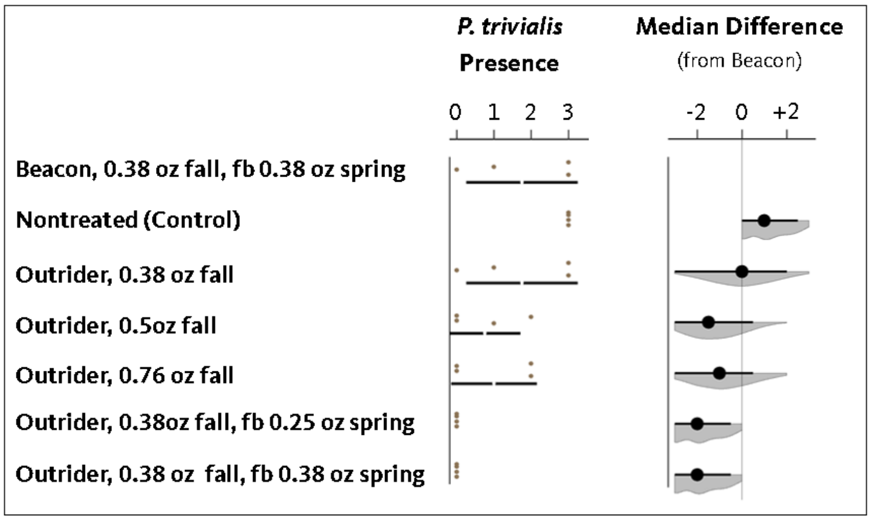

Figure 1. Roughstalk bluegrass presence at KBG heading. Presence was rated on a scale from 0 to 3, with no plants at 0 and highest density at 3. The plot on the left shows raw data for four replicate plots per trial (points), plus mean and standard deviation (bars). The plot on the right shows the median difference from the midpoint (median) of the Beacon reference treatment. Black bars are nonparametric 95% confidence intervals, and the gray curve is the sample error distribution for the interval estimate. Positive median difference values indicate more roughstalk bluegrass plants were present per plot than in the Beacon standard, and negative values indicate fewer.

At crop maturity, a 6-foot x 27-foot portion of each plot was swathed, allowed to dry in the field for 2–5 days, and threshed with a small plot combine. Samples were further processed with experimental-scale cleaning equipment (stationary thresher and air screen cleaner) to clean seed yield of approximately 98% purity and bushel weight of 21–23 lb/bu.

In Union County, a single field trial was established in a commercial field of ‘Gaelic’ planted in April 2021 in a fine sandy loam under wheel line irrigation. Outrider was applied postemergence at several rates (0.25, 0.38, 0.5, 0.76 oz/acre) at two application timings (two- to five-tiller and five- to eight-tiller KBG). Split applications were not evaluated at this site. The trial was arranged in a randomized complete block design with four replicates and individual plot size of 8 feet x 25 feet. Applications were made in 21 gal/acre using medium droplets with MSO at 1% v/v and AMS at 8.5 lb/100 gal. Trials were evaluated on a visual rating scale as previously described.

Results and Discussion

Warm-season grass control

Water shortages prevented full irrigation of the spring-seeded KBG field in which the Union County trial was located, and warm-season grass emergence was minimal. Evaluation of Outrider activity on warm-season grass weeds was thus not possible. Preliminary observations in other locations have indicated potential activity (data not shown), but confirmation will require further work. Crop safety was excellent, with minimal (≤ 5%) or no crop injury observed at any rate on either one-tiller or five-tiller KBG plants (data not shown). This trial is not considered further in this report.

Preemergent applications

Additional treatments in the five initial trial sites in Jefferson County included postplant preemergent applications of Outrider (0.38 and 0.76 oz/acre). At two locations, this application timing resulted in complete loss of KBG stands at both rates and no roughstalk bluegrass emergence (data not shown). At three locations, moderate to severe KBG injury was observed but not stand loss. The cause of major differences in crop safety at nearby locations on similar soils within the same year is unknown. Regardless, this application timing indicates that crop injury potential from Outrider likely increases markedly on early growth stages of KBG; thus, this timing does not warrant further investigation. The remainder of the discussion below considers only postemergence timings.

Roughstalk bluegrass control

Roughstalk bluegrass was present only at Site 2. By crop heading, control from fall applications of Outrider was equivalent to the Beacon standard treatment (Figure 1). Higher rates of fall-applied Outrider gave better control than the Beacon standard, but the relatively large degree of variability in the data precludes confident conclusion that this is a true difference. Split applications of Outrider (fall followed by spring) did improve control of roughstalk bluegrass relative to Beacon (Figure 1).

Kentucky bluegrass safety

Crop safety was evaluated in late April (KBG at second-node stage) and again during pollination. In April, crop safety differed notably between sites, with more severe crop injury at Site 2 from both Beacon and Outrider treatments (Figure 2). Relative differences among treatments, however, were fairly consistent across sites. By KBG head emergence, between-site differences had largely disappeared, and identical treatments showed similar levels of crop injury across sites.

In general, safety of the lower rates of fall-applied Outrider (0.38 and 0.5 oz/acre) was similar to that of the Beacon standard (Figure 2). At heading, Outrider at 0.76 oz/acre caused slightly higher crop injury than Beacon, with the difference evident mostly as reduced height and growth stage delays of approximately 1 week relative to the Beacon standard.

Split applications of Outrider had consistently higher injury than the Beacon standard, averaging approximately 10–15% higher, but with considerable variability around the average. Again, injury presented primarily as crop stunting and delayed crop development, but there was some visible reduction in panicle size as well. Patterns of crop safety were generally consistent with differences in observed seed yield.

Kentucky bluegrass yield

Clean seed yield was equivalent to the Beacon standard for fall Outrider at 0.38 and 0.5 oz/acre, while the 0.76 oz/acre rate reduced seed yield by nearly 25% (Figure 3). Split applications of Outrider also reduced seed yield by approximately 10 to 15%, depending on rate.

In both split Outrider treatments and the 0.76 oz/acre fall Outrider treatment, maturity was delayed by an estimated 3–5 days relative to the rest of the treatments. Swathing was done at a single timing, based on the surrounding field, which corresponded well to the Beacon standard but was not ideal for all Outrider treatments. This earlier-than-optimal swathing for some Outrider treatments might explain some of the yield reduction relative to the standard, but not all.

No effect was observed on seed germination rates from application of Beacon or Outrider (data not shown).

Discussion

Outrider offers a suitable option for control of roughstalk bluegrass in seedling KBG seed production fields. Across trial years, fall applications of Outrider at 0.38 or 0.5 oz/acre provided good crop safety and offered levels of roughstalk bluegrass control broadly comparable to Beacon in most cases.

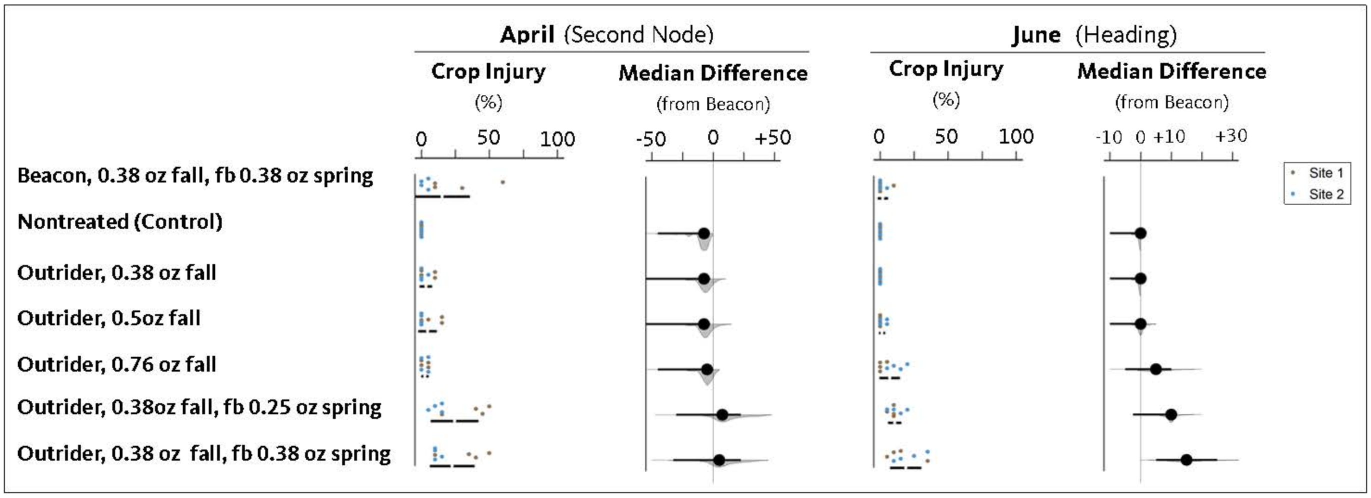

Figure 2. KBG injury from herbicide treatments at second-node and heading growth stages. Injury was rated on a scale of 0 to 100%, with no injury at 0 and complete plant death at 100%. The plot on the left shows raw data for four replicate plots per trial (points), plus mean and standard deviation (bars). The plot on the right shows the median difference from the midpoint (median) of the Beacon reference treatment. Black bars are nonparametric 95% confidence intervals, and the gray curve is the sample error distribution for the interval estimate. Positive median difference values indicate more crop injury than the Beacon standard, and negative values indicate less.

Fall applications of 0.76 oz/acre Outrider gave equivalent to slightly improved control of roughstalk bluegrass relative to split applications of Beacon but at the cost of higher potential for crop yield loss. Actual loss varied from year to year: from 0 to as much as approximately 25% yield reduction. This contrasts with results from four trial locations in the 2020 crop year, in which fall applications at this rate did not reduce clean seed yield (Spring and Affeldt, 2021). Both Beacon and Outrider are known to have year-to-year variability in crop injury, presumably due to complex and unpredictable interactions with environmental conditions, even with favorable weather windows for application occurring in both study years. It is assumed that such environmental variation was responsible for year-to-year differences in crop injury from the same application pattern. This observed variability is a valuable measure and can be interpreted as representing the range of likely outcomes that can be expected from year to year with fall applications of Outrider.

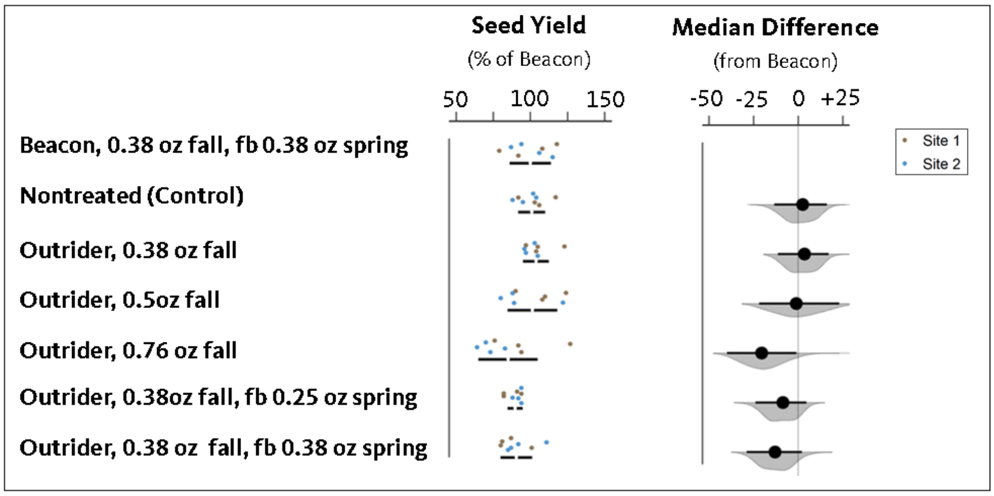

Figure 3. KBG clean seed yield (21–23 lb/bu and approximately 98% purity). The plot on the left shows raw data for four replicate plots per trial (points), plus mean and standard deviation (bars). The plot on the right shows the median difference from the midpoint (median) of the Beacon reference treatment. Black bars are nonparametric 95% confidence intervals, and the gray curve is the sample error distribution for the interval estimate. Positive median difference values indicate higher yield than the Beacon standard, and negative values indicate lower yield.

Split applications of Outrider (fall followed by spring) reduced KBG seed yield by approximately 10% (and approximately 20% across 2020 trials) but provided consistently better control of roughstalk bluegrass than the Beacon standard (both years).

All plots required supplemental hand-rogueing to attain full control of roughstalk bluegrass.

Use Recommendations

Note: The current 24c label (SLN No. OR-220002) should be read thoroughly prior to making any application of Outrider to KBG. Summary recommendations that follow will not be complete without a full understanding of the label.

Roughstalk bluegrass control in seedling KBG stands

Outrider may be applied in KBG up to 0.76 oz/acre total per crop year. One option is to apply Outrider as a single application of 0.38–0.76 oz/acre in the fall once KBG plants have at least two tillers but prior to winter dormancy. Alternatively, Outrider may be applied in a split pattern, including a fall application of 0.38 oz/acre followed by an application of 0.25–0.38 oz/acre in the spring between green-up and second-node emergence.

For fields with light roughstalk bluegrass pressure, the most conservative approach is probably a fall application of 0.5 oz/acre. This rate should reliably provide acceptable crop safety regardless of annual weather variation, and it leaves 0.25 oz/acre of the seasonal use maximum for a spring follow-up if needed. In trials to date, any given rate of Outrider has had variable activity (both crop injury and roughstalk bluegrass control) from year to year, presumably due to differences in environmental conditions between years.

In years in which Outrider is more “active,” both efficacy on roughstalk bluegrass and crop injury are higher. In such years, the 0.5 oz/acre rate applied in the fall may provide adequate roughstalk bluegrass control, and crop injury likely would exceed tolerable levels at higher use rates. In years in which Outrider activity is lower (reducing both roughstalk bluegrass control and crop injury), the remainder of the seasonal use maximum can be applied in the spring to obtain improved control with acceptable crop safety.

In fields with moderate to heavy roughstalk bluegrass pressure, economic loss will undoubtedly be sustained either from excessive seed loss during cleaning or due to herbicide damage. Split applications of 0.38 oz/acre in both fall and spring are likely the best treatment option in this scenario.

All trial work for roughstalk bluegrass control included MSO at 1% v/v and AMS at 8.5 lb/100 gal. While the label also permits use of NIS, the more aggressive surfactant package used to date in trial work (MSO + AMS) is recommended for best control of roughstalk bluegrass, particularly if it has more than two tillers at time of application.

Warm-season grass control in spring-planted seedling KBG

While the efficacy of Outrider on warm-season annual grasses such as witchgrass and foxtail has not been confirmed experimentally, preliminary observations indicate that Outrider may have soil residual activity on these weed species, and postemergence activity is presumed as well. Limited trial work in spring-seeded stands to date suggests that patterns of crop safety should not differ substantially between fall-planted stands in central Oregon and spring-planted stands in northeastern Oregon as long as KBG plants are at a labeled growth stage when Outrider is applied. In the absence of sufficient data, our initial recommendation is to apply 0.38 oz/acre Outrider when KBG plants reach three tillers or when the first flush of summer annual grasses reach the three- to five-leaf size, whichever is later.

Downy brome control in established stands

Outrider is labeled for control or suppression of downy brome in wheat and other registered crops, and it has acceptable activity for this use in limited trials conducted in established KBG (Spring and Walenta, 2022). Best efficacy will be achieved by including Outrider at 0.67 oz/acre (wheat use rate) to 0.76 oz/acre (maximum KBG seasonal use rate) as part of an early postemergence tank mix applied to one- to two-leaf downy brome.

As with many ALS inhibitors used for control of downy brome, application timing is absolutely critical to obtaining acceptable control with Outrider, and applications to downy brome plants with more than two leaves can be expected to provide suppression only, not control. (Similar results should be expected from preemergent applications.)

A tank-mix partner from a different herbicide mode-of-action group with postemergence activity on downy brome (e.g., oxyfluorfen) is highly recommended. For best results, an effective preemergence herbicide program should be applied prior to watering back established stands, followed by the early postemergent Outrider tank-mix. Later follow-up applications of a PSII-inhibiting herbicide (e.g., terbacil) may be needed to obtain acceptable control of heavy downy brome infestations.

Cautions

While Outrider has some general similarities to Beacon, direct inferences about Outrider performance by analogy to Beacon may be ill founded. For example, the registered use rate for Outrider appears to be much closer to the limits of crop tolerance than the registered use rate for Beacon. Inadvertent over-label applications of Beacon (for instance, double rates in areas of accidental boom overlap) have been known to offer agronomically acceptable levels of crop safety in many situations; however, similar over-label rates of Outrider likely will result in severe crop injury.

Beacon is also well known to show increased crop injury in response to environmental stressors around the time of application, especially cold or freezing temperatures. Observations made during trials in central Oregon indicate that Outrider is considerably more likely to cause increased crop injury in this situation. If daily low temperatures fall below 30–32°F within 3–4 days on either side of Outrider application, risk of substantial crop injury increases dramatically, and unacceptable injury should be expected with lows below 28–29°F during this period.

Finally, Outrider has considerable potential for carryover injury to sensitive crops, a trait that should be considered prior to use. Consult the wheat section of the Section 3 Outrider label (found on the container) for specific crops and instructions. Plant-back restrictions for many sensitive crops listed approach 2 years.

Full cautions and restrictions for Outrider use in KBG can be found in the 24c SLN label, SLN No. OR-220002. Plant-back restrictions are found on the Section 3 label.

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INDAZIFLAM FOR MULTIYEAR GRASS WEED CONTROL IN STAND ESTABLISHMENT OF KENTUCKY BLUEGRASS GROWN FOR SEED

J.F. Spring and D.L. Walenta

Introduction

Controlling grass weeds is a consistent challenge in Kentucky bluegrass (*Poa pratensis* L.; KBG) seed production. While herbicides are available for grass weed control in both seedling and established KBG, currently registered products generally provide less-than-adequate control when applied as stand-alone treatments. Effective grass weed control often requires use of multiple herbicides in sequential application programs. Even with intensive herbicide programs, failure to control key grass weeds in KBG is common. Additionally, several widely used products have potential for crop injury and/or carryover injury to rotational crops.

Indaziflam is a relatively new herbicide with a unique activity profile that may have potential to improve weed control in KBG seed production. It is currently registered as Alion (Bayer Crop Science) for crop uses, including in orchard production and in established stands of several other perennial grasses grown for seed in Oregon. It is also registered as Rejuvra and Esplanade (Bayer Environmental Science) for use in rangeland and other noncrop perennial grasses.

Indaziflam is a preemergent herbicide with broad-spectrum weed control activity and excellent safety on established perennial plants. Good preemergence control of many annual broadleaf and grassy weeds—including downy brome and medusahead—has been demonstrated in rangeland for 2 to 3 years following a single application of indaziflam (Sebastian et al., 2016). Safety on established perennial grasses has been excellent.

In grass seed production, good crop safety has been demonstrated in established stands of several cool-season species in the Willamette Valley (Curtis et al., 2015). In recent growing seasons, widespread use in Willamette Valley grass seed crops has generally resulted in acceptable crop safety as well, provided adequate time is allowed between application and subsequent rainfall or irrigation events. Adequate safety has also been documented from fall applications made to well-established spring-planted perennial ryegrass seedlings in western Oregon (Curtis et al., 2017).

Initial testing of indaziflam applied after harvest to established KBG demonstrated acceptable crop safety in the Grande Ronde Valley in northeast Oregon (Walenta, 2017). However, the typical postharvest application window has several challenges in irrigated KBG seed production. Ash, carbon, and crop residue remaining after burning or flaming can tie up preemergence herbicides and reduce activity. Herbicides also require properly timed and adequate irrigation and/or precipitation for activation prior to weed emergence and to maintain activity during extended windows of weed germination and emergence. If adequate moisture is not present during this time frame, efficacy of preemergent herbicides is greatly reduced. Additionally, the long residual activity of indaziflam may pose carryover concerns to rotational crops if used later in the life of a stand.

If crop safety is adequate, application of indaziflam shortly after stand establishment has the potential to substantially improve grass weed control in both fall- and spring-planted KBG. Application conditions are generally more favorable for uniform coverage and for herbicide activation and prolonged activity at this time than in established stands, particularly postharvest The long residual activity of indaziflam means that a single application has the potential to provide durable, preemergence grass weed control into following years of the stand.

Making applications as soon after KBG emergence as possible would provide the best weed control with indaziflam, but there likely is a minimum KBG seedling size required for adequate crop safety. While safety of indaziflam on well-established perennial grasses has been thoroughly demonstrated, previous evaluation of indaziflam safety on perennial grass seedlings has been very limited, and no information exists for seedling KBG grown for seed in Oregon.

The objective of this study was to evaluate the crop safety of indaziflam applied at early crop growth stages during stand establishment of irrigated KBG grown for seed in central Oregon and in the Grande Ronde Valley in northeast Oregon.

Materials and Methods

Field trials were located in two commercial stands of KBG seeded in mid-August 2020, one in Jefferson County near Madras, OR, and one in Union County near La Grande, OR. The Jefferson County site was in a stand of 'Wildhorse' in a loam soil under wheel-line irrigation. In Union County, the trial was located in a stand of 'Midnight SLT' in a sandy loam soil under center pivot irrigation. Sites were chosen to be weed-free. All normal production inputs were applied across the trial by the hosting grower using normal production practices.

Trials were established in a randomized complete block design with four replicates and an individual plot size of 10 feet x 30 feet (Jefferson County) or 8 feet x 25 feet (Union County). Indaziflam was applied as Alion at 1, 2, and 3 oz/acre at each of three growth stages of KBG using CO_2-powered backpack sprayers delivering 15 (Jefferson County) or 21 (Union County) gal/acre. Growth stages of KBG were 3–5 leaf, 3–5 tiller, and 10+ tiller. Applications were made in Jefferson County on September 28 (2020), October 15 (2020), and March 10 (2021) and in Union County on September 10 (2020), October 1 (2020), and April 2 (2021).

Crop injury was rated periodically throughout the season on a percent scale from 0 to 100, with no effect at 0 and complete plant death at 100. At second node appearance in the spring, green canopy area was measured in each plot from nadir photos made from a constant height with a digital camera and monopod using Canopeo (Patrignani and Ochsner, 2015) in Matlab R2021a (Mathworks, Natick, MA).

At crop maturity, a 6-foot-wide swath in the center of each plot was windrowed with a modified small-plot swather and allowed to dry in the field prior to threshing with a small-plot combine. Seed was then rethreshed with a stationary thresher and cleaned with a small air-screen cleaner to approximately 98% purity and a bushel weight of 21–23 lb/bu for calculation of clean-seed yield.

Green-area values were analyzed for treatment differences within each site using an analysis of deviance of a fixed-effect beta regression model with the packages *betareg* 3.1-4 and *car* 3.0-7 in R 3.6.3 and yield values with fixed effects ANOVA in the package *car*. Data consistency with model assumptions was confirmed in base R using a Bartlett test for homogeneity of variance and via manual examination of quantile plots (normality of residuals). As overall treatment effect was significant in all models ($P < 0.01$), treatment means for both models were separated with a Tukey's multiple comparison procedure ($\alpha = 0.05$) in the package *emmeans* 1.4-5, and letter displays were generated with *multcompView* 0.1-8. Data plots were generated in *ggplot2* 3.3.0 in R.

Results and Discussion

Indaziflam applied at the three- to five-leaf stage of KBG caused unacceptably high injury at both sites (Figure 1). In Union County, this application timing resulted in almost complete stand loss at the 2 and 3 oz/acre rates and more than 50% seed yield reduction at the 1 oz/acre rate. In Jefferson County, yield reductions were not as severe but were still clearly unacceptable at higher rates. At both sites, a pattern of increasing damage with rate was evident. Considerable root pruning was also evident at the higher rates at both sites through much of the early growing season (data not shown).

In Union County, application of indaziflam fewer than 12 hours before irrigation is thought to be the cause of the severe damage observed at this site. Indaziflam is known to require 24–48 hours of binding time on dry soil to prevent leaching into the crop root zone and subsequent crop damage. Application timing in Jefferson County provided an approximately 24-hour binding window on dry soil after application, presumably resulting in less crop damage. Regardless, this application timing resulted in considerable crop injury in both trials.

Indaziflam applied at the three- to five-tiller stage did not reduce crop canopy coverage at the second-node stage at either site (Figure 1). Seed yield was reduced at higher rates at both locations. High variability between replicates precludes estimation of this reduction with confidence, but in these trials yield losses ranged from 200 to 400 lb/acre clean seed, depending on rate. In some cases, the potential for this amount of yield loss might be an acceptable trade-off for the improved grass weed control anticipated from indaziflam. However, considerably more research is needed to robustly characterize the potential impact of indaziflam used at this application timing.

Indaziflam applied in the spring around the time of crop green-up (10+ tiller growth stage) and 2–4 weeks before the first irrigation of the year had good crop safety at both sites (Figure 1). In Jefferson County, clean seed yield at the 1- and 2-oz/acre rates was equivalent to

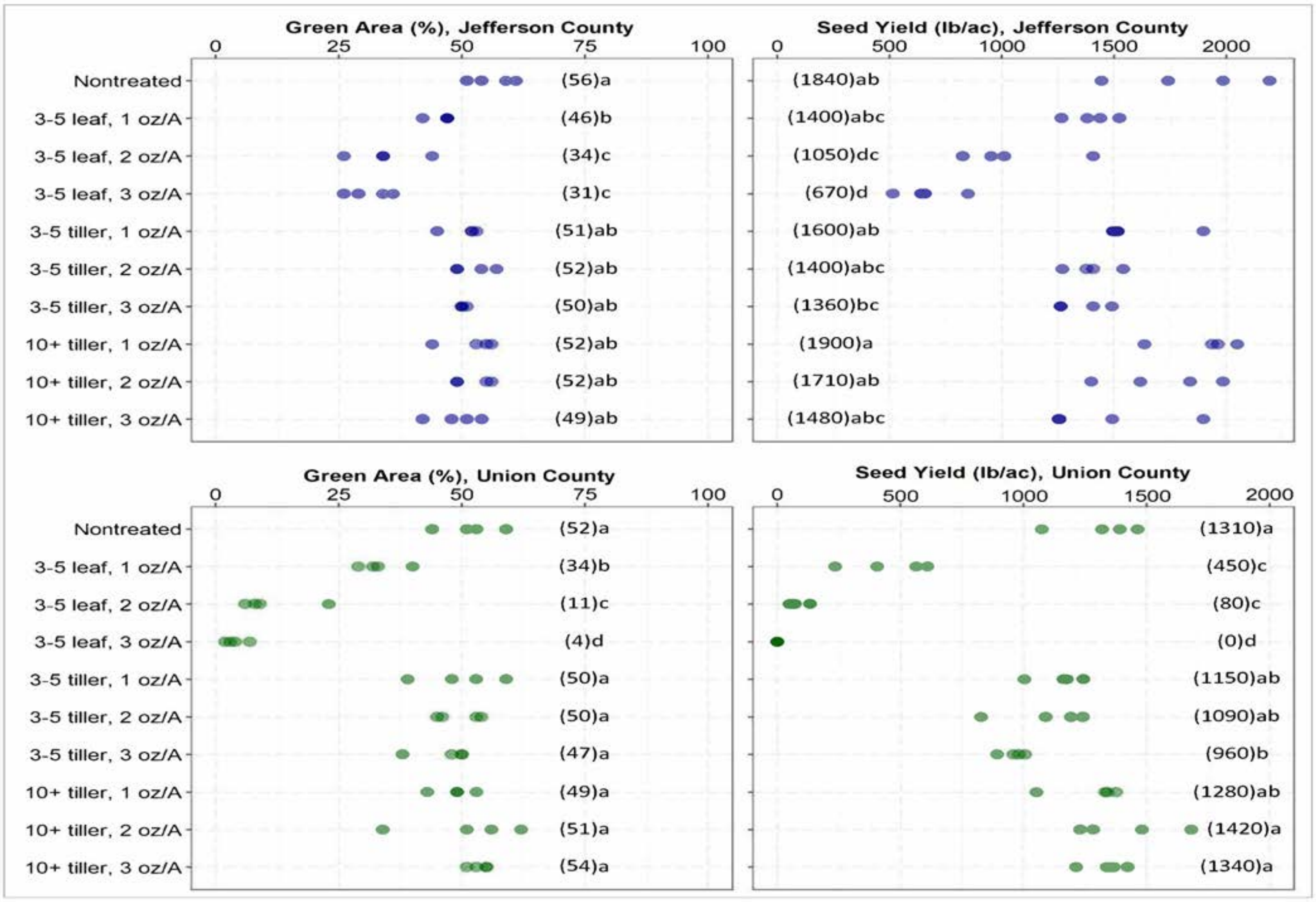

Figure 1. Left: canopy cover (measured as % green area) of Kentucky bluegrass at second-node growth stage in late April 2021. Right: clean seed yield (approximately 98% purity, 21 lb/bushel weight) for applications of indaziflam on seedling stands. Each point represents raw value for an individual plot, with four replicate plots per treatment at each site. Parenthetic values show overall treatment means. Within a plot, mean values followed by the same letter(s) are not different by Tukey's multiple comparison procedure (*P* = 0.05).

the nontreated check, with some reduction in yield at 3 oz/acre. Again, high variability among replicates within individual treatments (and particularly in the nontreated check in Jefferson County) cautions against overly confident interpretation on the basis of traditional statistical tests. In Union County, seed yield at all rates of indaziflam applied at this timing were equivalent to the nontreated check.

Overall, results of this initial study indicate that indaziflam has potential utility in seedling stands of KBG seed crops in Oregon and certainly warrants further investigation. Additional testing in a wider range of production environments is required before any reliable conclusions can be made regarding this possible use pattern, particularly regarding the crop safety of the applications made prior to tiller initiation or during early tiller development.

Note: Indaziflam is not currently registered for use in Kentucky bluegrass seed production. Mention of indaziflam in the context of this study is not to be considered a recommendation for commercial use.

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