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Author for correspondence:
Scott White. 50 Pictou Road, Truro, Nova Scotia B2N 2R8, Canada. Email: scott.white@dal.ca

Effects of fall bearing-year glufosinate applications, spring nonbearing-year glufosinate applications, and spring nonbearing-year foramsulfuron applications on hair fescue (*Festuca filiformis*) in lowbush blueberry

Scott N. White[1] and Linshan Zhang[2]

[1]Assistant Professor, Department of Plant, Food, and Environmental Sciences, Dalhousie University Faculty of Agriculture, Truro, NS, Canada and [2]Graduate student, Department of Plant, Food, and Environmental Sciences, Dalhousie University Faculty of Agriculture, Truro, NS, Canada.

Abstract

Hair fescue is a common perennial grass that reduces yields in lowbush blueberry fields. This grass is suppressed with nonbearing-year foramsulfuron applications, though suppression may be improved through use of sequential glufosinate and foramsulfuron applications. The objective of this research was to determine the main and interactive effects of fall bearing-year glufosinate applications, spring nonbearing-year glufosinate applications, and spring nonbearing-year foramsulfuron applications on hair fescue. The experiment was a 2 by 2 by 2 factorial arrangement of fall bearing-year glufosinate application (0, 750 g ai ha^{-1}), spring nonbearing-year glufosinate application (0, 750 g ai ha^{-1}), and spring nonbearing-year foramsulfuron application (0, 35 g ai ha^{-1}) arranged in a randomized complete block design at lowbush blueberry fields located in Parrsboro and Portapique, NS, Canada. Fall bearing-year glufosinate applications, spring nonbearing-year glufosinate applications, and spring nonbearing-year foramsulfuron applications alone provided inconsistent hair fescue suppression. Fall bearing-year glufosinate applications followed by spring nonbearing-year foramsulfuron applications, however, reduced nonbearing-year total tuft density, flowering-tuft density, and flowering-tuft inflorescence number at each site and reduced seed production at Portapique. Sequential fall bearing-year and spring nonbearing-year glufosinate applications or sequential spring nonbearing-year glufosinate and foramsulfuron applications reduced flowering-tuft density and flowering-tuft inflorescence number at each site but did not consistently reduce total tuft density. Sequential herbicide treatments reduced bearing-year seedling density and may therefore contribute to hair fescue seed bank management in lowbush blueberry.

Introduction

Lowbush blueberry is an economically important fruit crop in Canada that contributed $47.4 million CAD to farm gate value in 2017 (Anonymous 2019). The plant is a rhizomatous perennial shrub (Hall et al. 1979; Pritts and Hancock 1984), and commercial fields are developed from natural stands (Anonymous 2019). Fields are managed under a 2-yr production cycle in which plants are pruned to ground level by flail mowing in the first year (nonbearing year) (Eaton et al. 2004) and emerged shoots flower and produce berries in the second year (bearing year) (Wood 2004). Lack of tillage and crop rotation promotes the occurrence of perennial weeds (McCully et al. 1991), with the perennial grass hair fescue currently a weed of concern (Anonymous 2019).

Hair fescue is a common, caespitose (tuft-forming) perennial grass in lowbush blueberry fields. Tufts form dense sods that can reduce yield by >50% (White 2019; Zhang 2017; Zhang et al. 2018) and hinder mechanical harvesting. Control from PRE herbicides such as hexazinone and terbacil is limited or variable (White 2019; Yarborough and Cote 2014; Zhang et al. 2018), and fall pronamide applications provide the most effective control (White 2019; Yarborough and Cote 2014). High pronamide cost ($500 CAD ha^{-1}), however, limits grower adoption. Hair fescue can be suppressed with nonbearing-year POST foramsulfuron applications (White and Kumar 2017), though suppression is variable (Zhang et al. 2018). Suppression may be improved by use of sequential glufosinate and foramsulfuron applications, though glufosinate applications of 1,005 g ai ha^{-1} provide greater suppression than the currently registered maximum application rate of 750 g ai ha^{-1} (White and Kumar 2017).

Although limited to one application of 750 g ai ha^{-1} per year, the current glufosinate registration for lowbush blueberry in Canada allows for use of sequential fall bearing-year and spring nonbearing-year glufosinate applications of 750 g ai ha^{-1}. Sequential glufosinate applications improve control of many annual weed species (Aulakh and Jhala 2015; Beyers et al. 2002; Coetzer et al. 2002; Culpepper et al. 2000), including grass weeds such as volunteer corn (*Zea mays* L.) (Chahal and Jhala 2015), giant foxtail (*Setaria faberi* Herrm.) (Wiesbrook et al. 2001), wild-proso millet [*Panicum miliaceum* L. ssp. *ruderale* (Kitagawa) Tzevelev], and fall panicum (*Panicum dichotomiflorum* Michx.) (Van Wychen et al. 1999), as well as some perennials such as johnsongrass [*Sorghum halepense* (L.) Pers.] (Johnson et al. 2014; Landry et al. 2016). Sequential fall and spring glufosinate applications, alone or in conjunction with spring nonbearing-year foramsulfuron applications, however, have not been evaluated for hair fescue suppression in lowbush blueberry fields. The objective of this research was therefore to determine the main and interactive effects of fall bearing-year glufosinate applications, spring nonbearing-year glufosinate applications, and spring nonbearing-year foramsulfuron applications on hair fescue.

Materials and Methods

Study Sites and Experimental Design

The experiment was conducted in lowbush blueberry fields located at Parrsboro (45.43°N, 64.48°W) and Portapique (45.41°N, 63.72°W), NS, Canada, and was established on November 4, 2015 at Parrsboro and November 3, 2015 at Portapique. The experiment was a 2 by 2 by 2 factorial arrangement of fall glufosinate (Ignite herbicide; Bayer CropScience, Durham, NC) application (0 g ai, 750 g ai), spring glufosinate application (0 g a.i, 750 g a.i), and spring foramsulfuron (Option® 2.25 OD herbicide; Bayer CropScience Inc., Calgary, AB) application (0 g ai, 35 g ai) arranged in randomized complete block design with four blocks and 2 m by 6 m plot size at each site. Foramsulfuron was applied with a liquid nitrogen fertilizer (28% UAN) at a rate of 2.5 L ha^{-1}. Herbicides were applied using a CO_2-pressurized research plot sprayer outfitted with four Teejet 11002 XR nozzles (TeeJet Technologies, Spraying Systems Co., Springfield, PA) and calibrated to deliver a water volume of 200 L ha^{-1} at 276 kPa. Fall glufosinate treatments were applied on November 11, 2015 and November 10, 2015 at Parrsboro and Portapique, respectively. Spring glufosinate treatments were applied on May 13, 2016 and May 10, 2016 at Parrsboro and Portapique, respectively. Spring foramsulfuron treatments applied alone or after fall glufosinate applications were applied on May 13, 2016 and May 10, 2016 at Parrsboro and Portapique, respectively. Spring foramsulfuron treatments applied after spring glufosinate applications were applied on May 29, 2016 at Parrsboro and Portapique.

Data Collection

Data collection included hair fescue tuft density prior to treatment applications, vegetative and flowering hair fescue tuft density in summer of the nonbearing and bearing year, hair fescue flowering-tuft inflorescence number in summer of the nonbearing year, hair fescue seed production in fall of the nonbearing year, hair fescue seedling density in early summer of the bearing year, lowbush blueberry stem density, stem height, and flower bud number per stem at the end of the nonbearing year, and lowbush blueberry yield in late summer of the bearing year. Hair fescue tuft densities were determined in two 1-m by 1-m quadrats per plot. Hair fescue inflorescence number was determined on 10 randomly selected tufts per plot using a line transect method previously described (White and Kumar 2017). Hair fescue seed production was determined by collecting all inflorescences from five randomly selected hair fescue tufts in each plot and counting all seeds retained in the collected inflorescences. Hair fescue seedling densities were counted in three 30-cm by 30-cm quadrats per plot. Initial hair fescue tuft densities in treatments receiving fall bearing-year herbicide applications were determined on November 11, 2015 and November 10, 2015 at Parrsboro and Portapique, respectively. Initial hair fescue tuft densities in treatments receiving spring nonbearing-year herbicide applications were determined on April 27, 2016 at Parrsboro and Portapique. Nonbearing-year hair fescue flowering- and vegetative-tuft densities were determined on June 28, 2016 at Parrsboro and June 27, 2016 at Portapique. Nonbearing-year flowering hair fescue tuft inflorescence number was determined on July 11, 2016 at Parrsboro and July 8, 2016 at Portapique. Hair fescue inflorescences were collected for seed production estimation on October 8, 2016 at Parrsboro and October 20, 2016 at Portapique. Hair fescue seedling densities in the bearing year were determined on May 29, 2017 at Parrsboro and May 24, 2017 at Portapique. Bearing-year hair fescue flowering and vegetative tuft densities were determined on July 10, 2017 at Parrsboro and June 29, 2017 at Portapique.

Lowbush blueberry stem density was determined in three 30-cm by 30-cm quadrats per plot. Lowbush blueberry stem height and flower bud number per stem were determined on 30 randomly selected blueberry stems per plot. Stems were clipped at ground level, bagged in the field, and brought back to the lab for data collection. Lowbush blueberry yield was determined in two 1-m by 1-m quadrats per plot, and fruit was harvested using hand rakes. Lowbush blueberry stem density was determined on October 5, 2016 at Parrsboro and on October 20, 2016 at Portapique. Stem collections for height and flower bud assessment at each site occurred on these dates as well. Lowbush blueberry yield was determined on August 14, 2017 at Parrsboro and August 2, 2017 at Portapique.

Statistical Analysis

The main effects of site, fall glufosinate applications, spring glufosinate applications, spring foramsulfuron applications, and the subsequent interactions on the various response variables were determined using ANOVA in PROC MIXED in SAS for Windows (Statistical Analysis System, version 9.4, SAS Institute, Cary, NC). Main and interaction effects were modeled as fixed effects in the analysis, and blocks were modeled as a random effect. Assumptions of normality and constant variance for all analyses were assessed using PROC UNIVARIATE in SAS, and data were LOG(Y) or SQRT(Y) transformed where necessary to achieve normality and constant variance. Means separation, where necessary, was conducted using a Tukey's test at a probability level of $\alpha < 0.05$.

Results and Discussion

Treatment Effects on Hair Fescue

There was a significant effect of site on nonbearing-year flowering-tuft density ($P = 0.0182$), flowering-tuft inflorescence number ($P < 0.0001$), and flowering-tuft seed production ($P < 0.0001$), as well as a significant site-by-spring foramsulfuron effect on

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Table 1. P-values indicating significance of main and interactive effects of fall bearing-year glufosinate applications, spring nonbearing-year glufosinate applications, and spring nonbearing-year foramsulfuron applications on nonbearing-year hair fescue total tuft density, flowering-tuft density, flowering-tuft inflorescence number, and seed production in lowbush blueberry fields at Parrsboro and Portapique, NS, Canada.

Site	Effect	Total tuft density	Flowering-tuft density	Inflorescence number	Seed production
Parrsboro	Fall bearing-year glufosinate	0.0015[a]	0.0130	0.0002	0.2631
	Spring nonbearing-year glufosinate	0.0844	< 0.0001	< 0.0001	0.2356
	Fall bearing-year glufosinate × spring nonbearing-year glufosinate	0.4768	0.1147	0.0181	0.0369
	Spring nonbearing-year foramsulfuron	0.0003	< 0.0001	< 0.0001	0.0050
	Fall bearing-year glufosinate × spring nonbearing-year foramsulfuron	0.2594	0.6850	0.9293	0.6587
	Spring nonbearing-year glufosinate × spring nonbearing-year foramsulfuron	0.4553	0.0006	0.163	0.1347
	Fall bearing-year glufosinate × spring nonbearing-year glufosinate × spring nonbearing-year foramsulfuron	0.7476	0.7453	0.67528	0.5522
Portapique	Fall bearing-year glufosinate	0.0047	0.0005	0.0176	0.0596
	Spring nonbearing-year glufosinate	0.2173	0.0010	< 0.0001	< 0.0001
	Fall bearing-year glufosinate × spring nonbearing-year glufosinate	0.3475	0.6378	0.3216	0.2381
	Spring nonbearing-year foramsulfuron	0.0020	0.0005	0.0048	0.0038
	Fall bearing-year glufosinate × spring nonbearing-year foramsulfuron	0.2485	0.4690	0.1616	0.2637
	Spring nonbearing-year glufosinate × spring nonbearing-year foramsulfuron	0.2377	0.6263	0.1083	0.2714
	Fall bearing-year glufosinate × spring nonbearing-year glufosinate × spring nonbearing-year foramsulfuron	0.4376	0.1583	0.2033	0.0034

[a]P-values obtained from an ANOVA analysis using PROC MIXED in SAS. Main and interactive effects considered significant at $P < 0.05$.

nonbearing-year flowering-tuft density ($P = 0.0085$) and a significant site-by-spring glufosinate ($P < 0.0001$) and site-by-fall glufosinate-by-spring glufosinate-by-spring foramsulfuron effect ($P = 0.0211$) on nonbearing-year flowering-tuft seed production. There was also a significant site effect on bearing-year total tuft density ($P < 0.0001$) and flowering-tuft density ($P < 0.0001$), as well as a significant site-by-fall glufosinate-by-spring glufosinate-by-spring foramsulfuron effect ($P = 0.0481$) on bearing-year total tuft density. Sites were therefore analyzed separately in the analysis.

Nonbearing-year total tuft density was only affected by fall bearing-year glufosinate applications and spring nonbearing-year foramsulfuron applications at each site (Table 1), and data were therefore pooled by these main effects for analysis. Nonbearing-year flowering-tuft density and flowering-tuft inflorescence data were affected by all main effects at each site (Table 1), and there was a significant spring nonbearing-year glufosinate-by-spring nonbearing-year foramsulfuron effect on flowering-tuft density and a significant fall bearing-year glufosinate-by-spring nonbearing-year glufosinate effect on flowering-tuft inflorescence number at Parrsboro (Table 1). These data were therefore analyzed and presented based on the full factorial analysis. Nonbearing-year flowering-tuft seed production was also affected by various main and interactive effects, and data were also analyzed and presented based on the full factorial analysis.

Bearing-year total and flowering-tuft density were not affected by any main and interactive effects at Parrsboro (Table 2). Seedling density at this site was affected by spring nonbearing-year glufosinate applications and spring nonbearing-year foramsulfuron applications (Table 2), and data were therefore pooled across these main effects for analysis. Bearing-year total tuft density at Portapique was affected by fall bearing-year glufosinate applications and spring nonbearing-year foramsulfuron applications (Table 2), and data were pooled across these main effects for analysis. Bearing-year flowering-tuft density and seedling density at Portapique were affected by all main effects, and there was a significant fall bearing-year glufosinate-by-spring nonbearing-year glufosinate-by-spring nonbearing-year foramsulfuron effect on seedling density as well (Table 2). These data were therefore analyzed and presented based on the full factorial analysis.

Initial hair fescue tuft density at each site was 48 ± 11 and 15 ± 7 tufts m^{-2} at Parrsboro and Portapique, respectively. Spring foramsulfuron applications alone did not reduce nonbearing-year total tuft density at Parrsboro but did reduce total tuft density by >50% at Portapique (Table 3). Inconsistent or limited reductions in total tuft density from foramsulfuron are common (White and Kumar 2017; White 2019; Zhang et al. 2018), as this herbicide is generally only lethal to small hair fescue seedlings (White and Kumar 2017; White 2018) and great variability in hair fescue tuft size exists in field populations (S.N. White, unpublished data). Lower initial tuft density at Portapique may have also improved foramsulfuron efficacy at this site relative to Parrsboro. Spring foramsulfuron applications reduced flowering-tuft density, flowering-tuft inflorescence number, and seed production at Parrsboro (Table 4) but not Portapique (Table 5). Similar inconsistency in suppression has occurred in previous research (White 2019; Zhang et al. 2018). Reasons for this are again unclear, though variability in tuft size mentioned above likely contributes to this. Hair fescue tufts also appear to exhibit variable rates of development in the spring, with coexistence of both vegetative and bolting tufts common in early spring (S.N. White, unpublished data). This variability in tuft size and development, though as yet undocumented, likely contributes to variability in herbicide efficacy that may explain differences in tuft density reductions across sites. Foramsulfuron suppression was also limited to the nonbearing year, as there were no significant main or interactive effects on bearing-year hair fescue total tuft density or flowering-tuft density at Parrsboro (Table 2; mean total and flowering-tuft density of 23 ± 1 and 16 ± 1 tufts m^{-2}, respectively), and bearing-year total tuft density and flowering-tuft density were not reduced by foramsulfuron at Portapique (Tables 6 and 7). Bearing-year hair fescue seedling density, however, was reduced at Parrsboro (Table 8), indicating that reductions in nonbearing-year seed production by foramsulfuron (Table 4) may reduce bearing-year seedling populations. Fall bearing-year glufosinate applications reduced total tuft density at Portapique but not Parrsboro (Table 3), indicating that fall glufosinate applications may contribute to density reductions in fields with tuft density similar to that of Portapique. Nonbearing-year flowering-tuft density and seed production, however, were not reduced by fall bearing-year glufosinate applications at either site (Tables 4 and 5), and flowering-tuft inflorescence number was only reduced at Parrsboro (Table 4). Similar results were

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Table 2. P-values indicating significance of main and interactive effects of fall bearing-year glufosinate applications, spring nonbearing-year glufosinate applications, and spring nonbearing-year foramsulfuron applications on bearing-year hair fescue total tuft density, flowering-tuft density, and seedling density in lowbush blueberry fields at Parrsboro and Portapique, NS, Canada.

Site	Effect	Total tuft density	Flowering-tuft density	Seedling density
Parrsboro	Fall bearing-year glufosinate	0.6472[a]	0.2443	0.1056
	Spring nonbearing-year glufosinate	0.5723	0.7406	0.0040
	Fall bearing-year glufosinate × spring nonbearing-year glufosinate	0.3237	0.5096	0.9701
	Spring nonbearing-year foramsulfuron	0.2326	0.0520	< 0.0001
	Fall bearing-year glufosinate × spring nonbearing-year foramsulfuron	0.0903	0.2631	0.6767
	Spring nonbearing-year glufosinate × spring nonbearing-year foramsulfuron	0.2754	0.6368	0.1587
	Fall bearing-year glufosinate × spring nonbearing-year glufosinate × spring nonbearing-year foramsulfuron	0.0903	0.3257	0.1806
Portapique	Fall bearing-year glufosinate	0.0051	0.0029	0.0001
	Spring nonbearing-year glufosinate	0.0932	< 0.0001	0.0001
	Fall bearing-year glufosinate × spring nonbearing-year glufosinate	0.5015	0.4298	0.6262
	Spring nonbearing-year foramsulfuron	0.0124	0.0021	0.0006
	Fall bearing-year glufosinate × spring nonbearing-year foramsulfuron	0.8470	0.1036	0.0667
	Spring nonbearing-year glufosinate × spring nonbearing-year foramsulfuron	0.1576	0.1984	0.7830
	Fall bearing-year glufosinate × spring nonbearing-year glufosinate × spring nonbearing-year foramsulfuron	0.1116	0.2185	0.0288

[a]P-values obtained from an ANOVA analysis using PROC MIXED in SAS. Main and interactive effects considered significant at $P < 0.05$.

Table 3. Effect of fall bearing-year glufosinate and spring nonbearing-year foramsulfuron applications on nonbearing- year hair fescue total tuft density in lowbush blueberry fields located at Parrsboro and Portapique, NS, Canada.

Site	Fall glufosinate application	Spring foramsulfuron application	Total tuft density
			No. tufts m^{-2}
Parrsboro	No	No	19 ± 3 a[a]
	No	Yes	14 ± 3 a
	Yes	No	15 ± 3 a
	Yes	Yes	5 ± 3 b
Portapique	No	No	22 ± 3 a
	No	Yes	11 ± 3 b
	Yes	No	12 ± 3 b
	Yes	Yes	7 ± 3 b

[a]Values represent the mean ± 1 SE. Means within the same column for each site followed by the same letter are not significantly different according to a Tukey's multiple means comparison test at $P < 0.05$.

reported by White (2019), and collectively these results indicate that surviving tufts can recover and flower following fall bearing-year glufosinate applications. Spring nonbearing-year glufosinate applications did not affect nonbearing-year total tuft density at either site (Table 1) and did not reduce flowering-tuft density, flowering-tuft inflorescence number, or seed production at Portapique (Table 5). Spring nonbearing-year glufosinate applications, however, reduced both flowering-tuft density and flowering-tuft inflorescence number at Parrsboro (Table 4). Fall bearing-year and spring nonbearing-year glufosinate applications tend to exhibit variable efficacy on hair fescue (White and Kumar 2017; White 2019). Our results reflect this and further confirm that fall or spring glufosinate applications alone do not provide reliable hair fescue suppression in lowbush blueberry. Suppression of established tufts was also limited primarily to the nonbearing year, as bearing-year total tuft density and flowering-tuft density were not affected by glufosinate applications at Parrsboro (Table 2) and were not reduced by fall bearing-year or spring nonbearing-year glufosinate applications at Portapique (Tables 6 and 7). Bearing-year seedling density was, however, reduced by spring nonbearing glufosinate applications at Parrsboro (Table 8). Although seed production was not reduced at this site (Table 4), spring glufosinate applications can reduce hair fescue seed viability (White and Kumar 2017), which may have contributed to reduced seedling density.

Fall bearing-year glufosinate applications followed by spring nonbearing-year foramsulfuron applications reduced total tuft density, flowering-tuft density, and flowering-tuft inflorescence number at each site (Tables 3, 4, and 5) and reduced seed production at Portapique (Table 5). This treatment also gave more consistent hair fescue suppression across sites than spring nonbearing-year foramsulfuron applications alone (Tables 3, 4, and 5). Spring nonbearing-year glufosinate applications followed by spring nonbearing-year foramsulfuron applications also reduced flowering-tuft density and flowering-tuft inflorescence number at each site (Tables 4 and 5) and reduced seed production at Portapique (Table 5). This treatment, however, did not reduce total tuft density. These results indicate that growers could consider sequential glufosinate and foramsulfuron applications to improve nonbearing-year hair fescue suppression but should use fall bearing-year rather than spring nonbearing-year glufosinate applications as a result of greater reductions in total tuft density. White and Kumar (2017) also found that spring nonbearing-year glufosinate applications followed by foramsulfuron did not reduce total tuft density, further indicating that fall bearing-year glufosinate applications may be more effective than spring nonbearing-year applications if used in conjunction with spring nonbearing-year foramsulfuron applications. Fall bearing-year glufosinate applications followed by spring nonbearing-year foramsulfuron applications also reduced bearing-year total tuft density, flowering-tuft density, and seedling density at Portapique (Tables 6 and 7). From a practical perspective, fall bearing-year glufosinate applications are more amenable to lowbush blueberry production than spring nonbearing-year applications, as most growers balance spring nonbearing-year herbicide applications with spring bearing-year monilinia [*Monilinia vaccinia-corymbosi* (Reade)] and botrytis (*Botrytis cinerea* Pers.: Fr.) blight management (Delbridge and Hildenbrand 1995; Hildebrand et al. 2001) and may not have the resources to conduct additional spring herbicide applications.

Despite lack of a spring nonbearing-year glufosinate effect on nonbearing-year total tuft density (Table 1), sequential fall

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Table 4. Effect of fall bearing-year glufosinate applications, spring nonbearing-year glufosinate applications, and spring nonbearing-year foramsulfuron applications on nonbearing-year hair fescue flowering-tuft density, flowering-tuft inflorescence number, and flowering-tuft seed production at Parrsboro, NS, Canada.

Fall glufosinate application	Spring glufosinate application	Spring foramsulfuron application	Flowering-tuft density	Inflorescence number[a]	Seed production[b]
			No. tufts m^{-2}	No. per tuft	No. seeds per tuft
No	No	No	14 ± 1 a[c]	3.6 ± 0.2 (12) a	8.6 ± 4.4 (90) ab
No	No	Yes	4 ± 1 b	2.5 ± 0.2 (6) b	6.3 ± 4.4 (54) b
No	Yes	No	5 ± 1 b	2.2 ± 0.2 (4) bc	17.5 ± 4.4 (410) a
No	Yes	Yes	1 ± 1 b	1.6 ± 0.2 (2) bc	8.4 ± 4.4 (84) ab
Yes	No	No	10 ± 1 a	2.4 ± 0.2 (5) b	14.2 ± 4.4 (315) ab
Yes	No	Yes	1 ± 1 b	1.4 ± 0.2 (1) bc	11.4 ± 4.4 (180) ab
Yes	Yes	No	4 ± 1 b	1.9 ± 0.2 (3) bc	14.1 ± 4.4 (318) ab
Yes	Yes	Yes	0 b	1.3 ± 0.2 (1) c	8.3 ± 4.4 (90) ab

[a]Inflorescence number data were SQRT(Y) transformed to meet the assumptions of the variance analysis. Transformed means are presented for variance estimates and means comparison purposes, and back-transformed means are presented in parentheses.
[b]Seed number data were SQRT(Y) transformed to meet the assumptions of the variance analysis. Transformed means are presented for variance estimates and means comparison purposes, and back-transformed means are presented in parentheses.
[c]Values represent the mean ± 1 SE. Means within the same column followed by the same letter are not significantly different according to a Tukey's multiple means comparison test at $P < 0.05$.

Table 5. Effect of fall bearing-year glufosinate applications, spring nonbearing-year glufosinate applications, and spring nonbearing-year foramsulfuron applications on nonbearing-year hair fescue flowering-tuft density, flowering-tuft inflorescence number, and flowering-tuft seed production at Portapique, NS, Canada.

Fall glufosinate application	Spring glufosinate application	Spring foramsulfuron application	Flowering-tuft density[a]	Inflorescence number[b]	Seed production
			No. tufts m^{-2}	No. per tuft	No. seeds per tuft
No	No	No	2.7 ± 0.3 (16) a[c]	5.2 ± 0.5 (27) a	1453 ± 234 a
No	No	Yes	1.9 ± 0.3 (6) ab	4.8 ± 0.5 (22) ab	1463 ± 234 a
No	Yes	No	1.9 ± 0.3 (9) ab	3.5 ± 0.5 (12) abc	769 ± 234 ab
No	Yes	Yes	1.6 ± 0.3 (4) b	3.1 ± 0.5 (9) bc	149 ± 234 b
Yes	No	No	2 ± 0.3 (8) ab	4.9 ± 0.5 (25) a	1634 ± 234 a
Yes	No	Yes	1.4 ± 0.3 (4) bc	2.9 ± 0.5 (8) c	356 ± 234 b
Yes	Yes	No	1.5 ± 0.3 (4) bc	3 ± 0.5 (9) c	344 ± 234 b
Yes	Yes	Yes	0.6 ± 0.3 (1) c	2.3 ± 0.5 (5) c	349 ± 234 b

[a]Flowering-tuft density data were LOG(Y) transformed to meet the assumptions of the variance analysis. Transformed means are presented for variance estimates and means comparison purposes, and back-transformed means are presented in parentheses.
[b]Flowering-tuft inflorescence number data were LOG(Y) transformed to meet the assumptions of the variance analysis. Transformed means are presented for variance estimates and means comparison purposes, and back-transformed means are presented in parentheses.
[c]Values represent the mean ± 1 SE. Means within the same column followed by the same letter are not significantly different according to a Tukey's multiple means comparison test at $P < 0.05$.

Table 6. Effect of fall bearing-year glufosinate and spring nonbearing-year foramsulfuron applications on bearing-year hair fescue total tuft density at Portapique, NS, Canada.

Fall glufosinate application	Spring foramsulfuron application	Total tuft density
		No. tufts m^{-2}
No	No	14 ± 2 a[a]
No	Yes	11 ± 2 ab
Yes	No	10 ± 2 ab
Yes	Yes	7 ± 2 b

[a]Values represent the mean ± 1 SE. Means within the same column followed by the same letter are not significantly different according to a Tukey's multiple means comparison test at $P < 0.05$.

bearing-year and spring nonbearing glufosinate applications reduced flowering-tuft density and flowering-tuft inflorescence number at each site (Tables 4 and 5) and reduced seed production at Portapique (Table 4). This glufosinate use pattern therefore seems to provide better hair fescue suppression than a single spring glufosinate application of 1,005 g ha^{-1}, as this application rate did not reduce total tuft density or flowering-tuft density (White and Kumar 2017). Fall bearing-year glufosinate applications followed by spring nonbearing-year foramsulfuron applications, however, consistently reduced total tuft density in addition to flowering-tuft density and flowering-tuft inflorescence number (Tables 3, 4, and 5), indicating that fall bearing-year glufosinate applications should be followed by spring nonbearing-year foramsulfuron applications rather than spring nonbearing-year glufosinate applications. Sequential fall bearing-year and spring nonbearing-year glufosinate applications followed by spring nonbearing-year foramsulfuron applications were also similar in efficacy to fall bearing-year glufosinate applications followed by spring nonbearing-year foramsulfuron applications (Tables 4 and 5), again indicating that fall bearing-year glufosinate applications alone are adequate if followed by spring nonbearing-year foramsulfuron applications.

Treatment Effects on Lowbush Blueberry

There were no significant main or interactive effects on lowbush blueberry stem density, stem height, flower bud number, or yield at Parrsboro (Table 9). Average stem density, stem height, flower bud number, and yield at this site were 410 ± 10 stems m^{-2}, 18 ± 0.5 cm, 7.5 ± 0.5 buds per stem, and 2,038 ± 126 kg ha^{-1}, respectively. There were also no significant main or interactive effects on lowbush blueberry stem density or height at Portapique (Table 9), and stem density and height averaged 289 ± 10 stems m^{-2} and 16 ± 1 cm, respectively. There was,

Table 7. Effect of fall bearing-year glufosinate applications, spring nonbearing-year glufosinate applications, and spring nonbearing-year foramsulfuron applications on bearing-year hair fescue flowering-tuft density and seedling density at Portapique, NS, Canada.

Fall glufosinate application	Spring glufosinate application	Spring foramsulfuron application	Flowering-tuft density	Seedling density[a]
			No. tufts m^{-2}	No. seedlings m^{-2}
No	No	No	17 ± 3 a[b]	14 ± 1.8 (201) a
No	No	Yes	10 ± 3 ab	14 ± 1.8 (201) a
No	Yes	No	12 ± 3 ab	12.3 ± 1.8 (153) ab
No	Yes	Yes	13 ± 3 ab	9 ± 1.8 (82) abc
Yes	No	No	11 ± 3 ab	14 ± 1.8 (201) a
Yes	No	Yes	9 ± 3 b	7.2 ± 1.8 (52) bc
Yes	Yes	No	10 ± 3 ab	7.8 ± 1.8 (67) bc
Yes	Yes	Yes	6 ± 3 b	5.2 ± 1.8 (26) c

[a]Seedling density data were SQRT(Y) transformed to meet the assumptions of the variance analysis. Transformed means are presented for variance estimates and means comparison purposes, and back-transformed means are presented in parentheses.
[b]Values represent the mean ± 1 SE. Means within the same column followed by the same letter are not significantly different according to a Tukey's multiple means comparison test at $P < 0.05$.

Table 8. Effect of spring nonbearing-year glufosinate and spring nonbearing-year foramsulfuron applications on bearing-year hair fescue seedling density at Parrsboro, NS, Canada.

Spring glufosinate application	Spring foramsulfuron application	Seedling density
		No. seedlings m^{-2}
No	No	158 ± 14 a[a]
No	Yes	77 ± 14 b
Yes	No	102 ± 14 b
Yes	Yes	56 ± 14 b

[a]Values represent the mean ± 1 SE. Means within the same column for each site followed by the same letter are not significantly different according to a Tukey's multiple means comparison test at $P < 0.05$.

however, a significant spring nonbearing-year glufosinate effect on lowbush blueberry flower bud number and a significant fall bearing-year glufosinate and spring nonbearing-year glufosinate effect on lowbush blueberry yield at Portapique (Table 9). Data were therefore pooled by these effects for analysis. There was a significant spring nonbearing-year glufosinate effect on lowbush blueberry flower bud number ($P < 0.0001$), with flower bud number increasing from 4.7 ± 0.3 buds per stem in the absence of spring glufosinate applications to 6.3 ± 0.3 buds per stem following spring glufosinate applications ($t = -5.97$; $P < 0.0001$). Sequential fall bearing-year and spring nonbearing-year glufosinate applications also increased yield at Portapique relative to no glufosinate applications (Table 10). Results indicate that suppression of hair fescue increased yield at Portapique. Significance of glufosinate in the yield response may be linked to the injury it causes to weeds relative to foramsulfuron. Glufosinate injury is characterized by fairly rapid necrosis of treated leaf tissue (Anderson et al. 1993; Takano et al. 2019). Similar injury occurs to hair fescue (White and Kumar 2017; White 2018). Although not fatal to large tufts, this injury does reduce the existing hair fescue canopy until regrowth occurs (White and Kumar 2017). In contrast, foramsulfuron injury consists primarily of stunting and reduced overall growth, but treated plants maintain the leaf canopy present at the time of herbicide application (White and Kumar 2017). This difference in injury, particularly during spring of the nonbearing year when new blueberry shoots are emerging, may contribute to differential yield responses between these herbicides. In addition, new lowbush blueberry stems emerge from both rhizomes as well as lateral buds at the base of previously pruned stems (White et al. 2012). New shoots emerging from these lateral buds emerge before those arising from rhizomes (White et al. 2012) but yield fewer flower buds than those emerging from rhizomes (Ismail and Hanson 1982). Spring glufosinate applications may have killed the new shoots emerging from lateral buds, providing a "chemical pruning" effect that may have stimulated growth of new shoots from rhizomes, as the uneven terrain at the Portapique site did result in uneven cutting height of blueberry stems during pruning (S.N. White, personal communication).

In conclusion, fall bearing-year glufosinate applications, spring nonbearing-year glufosinate applications, and spring nonbearing-year foramsulfuron applications alone did not consistently reduce hair fescue total tuft density, flowering-tuft density, flowering-tuft inflorescence number, or seed production, and any suppression obtained was limited to the nonbearing year only. Fall bearing-year glufosinate applications followed by spring nonbearing-year foramsulfuron applications, however, reduced total tuft density, flowering-tuft density, and flowering-tuft inflorescence number at each site and reduced seed production at Portapique. This treatment also reduced bearing-year seedling density, providing evidence that damage to hair fescue in the nonbearing year can reduce seedling density in the subsequent bearing year. Spring nonbearing-year glufosinate applications followed by spring nonbearing-year foramsulfuron applications were less effective than fall bearing-year glufosinate applications followed by spring nonbearing-year foramsulfuron applications, suggesting that growers should use fall bearing-year glufosinate applications if considering use of sequential glufosinate and foramsulfuron applications for hair fescue management. Fall bearing-year glufosinate applications followed by spring nonbearing-year foramsulfuron applications were also more effective than sequential fall bearing-year and spring nonbearing-year glufosinate applications and provided efficacy similar to sequential fall bearing-year and spring nonbearing-year glufosinate applications followed by spring nonbearing-year foramsulfuron applications. Results therefore indicate that fall bearing-year glufosinate applications followed by spring nonbearing-year foramsulfuron applications are likely the best combination of these particular herbicides for hair fescue management in lowbush blueberry.

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Table 9. P-values indicating significance of main and interactive effects of fall bearing-year glufosinate applications, spring nonbearing-year glufosinate applications, and spring nonbearing-year foramsulfuron applications on lowbush blueberry stem density, stem height, flower buds per stem, and yield in lowbush blueberry fields at Parrsboro and Portapique, NS, Canada.

Site	Effect	Stem density	Stem height	Flower bud number	Yield
Parrsboro	Fall bearing-year glufosinate	0.1933[a]	0.4666	0.4550	0.1030
	Spring nonbearing-year glufosinate	0.5680	0.8720	0.2663	0.0933
	Fall bearing-year glufosinate × spring nonbearing-year glufosinate	0.7481	0.7676	0.9102	0.0620
	Spring nonbearing-year foramsulfuron	0.4290	0.3307	0.1291	0.8333
	Fall bearing-year glufosinate × spring nonbearing-year foramsulfuron	0.3979	0.2970	0.2587	0.6743
	Spring nonbearing-year glufosinate × spring nonbearing-year foramsulfuron	0.4617	0.7156	0.2297	0.9580
	Fall bearing-year glufosinate × spring nonbearing-year glufosinate × spring nonbearing-year foramsulfuron	0.7693	0.4324	0.5615	0.7130
Portapique	Fall bearing-year glufosinate	0.5358	0.1082	0.9598	0.0278
	Spring nonbearing-year glufosinate	0.0815	0.2993	0.0002	0.0278
	Fall bearing-year glufosinate × spring nonbearing-year glufosinate	0.0862	0.8135	0.5362	0.4542
	Spring nonbearing-year foramsulfuron	0.8059	0.4009	0.0731	0.4767
	Fall bearing-year glufosinate × spring nonbearing-year foramsulfuron	0.2605	0.1779	0.9598	0.1518
	Spring nonbearing-year glufosinate × spring nonbearing-year foramsulfuron	0.1620	0.0604	0.5146	0.1963
	Fall bearing-year glufosinate × spring nonbearing-year glufosinate × spring nonbearing-year foramsulfuron	0.0815	0.4616	0.9598	0.6791

[a]P-values obtained from an ANOVA analysis using PROC MIXED in SAS. Main and interactive effects considered significant at $P < 0.05$.

Table 10. Effect of fall bearing-year and spring nonbearing-year glufosinate applications on lowbush blueberry yield at Portapique, NS, Canada.

Fall glufosinate application	Spring glufosinate application	Yield
		kg ha^{-1}
No	No	2,713 ± 514 b[a]
No	Yes	3,238 ± 514 ab
Yes	No	3,238 ± 514 ab
Yes	Yes	4,263 ± 514 a

[a]Values represent the mean ± 1 SE. Means within the same column for each site followed by the same letter are not significantly different according to a Tukey's multiple means comparison test at $P < 0.05$.

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