Breeding and Evaluation of Fine Fescues for Increased Tolerance to Mesotrione Herbicide

Trent M. Tate¹, Stacy A. Bonos¹, and William A. Meyer¹

ADDITIONAL INDEX WORDS. annual bluegrass control, *Festuca*, *Festuca rubra* ssp. *commutata*, *Festuca brevipila*, *F. rubra* ssp. *rubra*, herbicide injury, recurrent selection

SUMMARY. Fine fescues (*Festuca* sp.) are a group of species that require fewer inputs, such as fertilizer, than other cool-season species managed for turf. They are adapted to infertile, acidic soils; shade; and drought. One area that poses additional challenges is the lack of weed control options for fine fescues during establishment from seed. Mesotrione is a herbicide that provides preemergence control of many broadleaf and grassy weeds, such as annual bluegrass (*Poa annua*), but is currently not labeled for use in fine fescues at seeding. The objectives of this research were 1) to use a recurrent selection technique to develop mesotrione-tolerant chewings fescue (*Festuca rubra* ssp. *commutata*), hard fescue (*Festuca brevipila*), and strong creeping red fescue (*F. rubra* ssp. *rubra*); and 2) to conduct field trials to compare the new selections to commercially available cultivars and experimental lines not selected for tolerance to mesotrione. Progress was made after each of the three generations of recurrent selection. The top statistical grouping of entries for injury following application of mesotrione at the 8-oz/acre rate included all the third-generation (G3) hard fescues, all the G3 chewings fescues, and the G3 strong creeping red fescue STB1 Composite. After three generations, selections of hard, chewings, and strong creeping red fescues had equivalent or better tolerance to mesotrione than tall fescue (*Festuca arundinacea*) and kentucky bluegrass (*Poa pratensis*) cultivars, which are on the label for safe use at seeding. These new selections would provide turf managers an option to control weeds using mesotrione during seedling establishment of fine fescues.

Fine fescues (*Festuca* sp.) are a group of cool-season turfgrass species that have a needle-like fine leaf texture and are well adapted to cool, humid regions of the world. They are also adapted to infertile, acidic soils; shade; and drought (Beard, 1973; Hanson et al., 1969; Turgeon, 1996). This group of species does well under lower fertility compared with other cool-season grasses (Ruemmele et al., 2003). The fine fescues have been found in a wide range of habitats, from beaches, dunes, coastal rock, cliffs, salt marshes, meadows, and grasslands (Pavlick, 1985). These traits

make them good choices for low-maintenance areas (Beard, 1973; Meyer and Funk, 1989; Turgeon, 1996). Once established, these species need few inputs to maintain a good turf stand.

Currently, there are very few options for preemergence weed control during seeding and establishment of fine fescues. Preemergence weed control before and during establishment is an important component to establish successfully a healthy stand of cool-season turfgrass (Beard, 1973; Musser and Perkins, 1969). Weeds compete for light, water, and nutrients, and usually have a much faster establishment and growth rate than fine fescues. The recommended timing for turfgrass establishment in New Jersey is 15 Aug. to 5

Oct. (Grande, 2004). This timing coincides with the peak emergence of annual bluegrass [*Poa annua* (Kaminski and Dernoeden, 2007)], which is what makes it the most problematic weed to control when establishing new cool-season turfgrasses in the northeastern United States. Having safe, selective pre-emergence control of annual bluegrass in fine fescues would increase the ability to establish these low-maintenance grasses successfully. Mesotrione is a 4-hydroxyphenylpyruvate dioxygenase-inhibiting herbicide that controls many monocot and dicot weeds selectively at seeding in many cool-season turfgrasses (Askew and Beam, 2002; Hart et al., 2007; Willis et al., 2006). Currently, mesotrione is the active ingredient in Tenacity (Syngenta Crop Protection, Greensboro, NC) which is labeled for use in many cool-season turfgrasses at rates of 2-4 oz/acre mesotrione. It is not currently labeled for use in fine fescues at seeding or for use in seed blends that contain more than 20% fine fescue (Syngenta Crop Protection, 2008). Mesotrione effectively provides preemergence control of both broadleaf and grassy weeds. Mesotrione can have several negative effects on fine fescues. Phototoxicity (bleaching of leaf tissue) is commonly associated with the use of mesotrione on fine fescue (Williams et al., 2009). In the study conducted by Williams et al. in 2009, they concluded that no rate or timing used in the study was safe to use on chewings fescue at seeding. These effects can impact significantly the ability of fine fescue seedlings to establish and survive.

There are previous examples of using recurrent selection in breeding fine fescues for increased tolerance to herbicides. Johnston and Faulkner (1986) developed the aminotriazole-tolerant 'Countess' chewings fescue to control annual bluegrass. Herbicide tolerance development in hard

Received for publication 4 Dec. 2020. Accepted for publication 16 Feb. 2021.

Published online 14 April 2021.

¹Department of Plant Biology, Rutgers, The State University of New Jersey, 59 Dudley Road, Foran Hall, New Brunswick, NJ 08901

We thank Ruying Wang, Ron Bara, Dirk Smith, Phillip Vines, and Ryan Daddio for their tremendous help with this research.

T.M.T. is the corresponding author. E-mail: trentmtate@gmail.com.

This is an open access article distributed under the CC BY-NC-ND license (<https://creativecommons.org/licenses/by-nc-nd/4.0/>).

<https://doi.org/10.21273/HORTTECH04772-20>

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
9.3540	gal/acre	L·ha ⁻¹	0.1069
2.54	inch(es)	cm	0.3937
48.8243	lb/1000 ft ²	kg·ha ⁻¹	0.0205
1.1209	lb/acre	kg·ha ⁻¹	0.8922
70.0532	oz/acre	g·ha ⁻¹	0.0143

fescue has been demonstrated previously with the nonselective herbicide glyphosate to develop 'Aurora Gold', which is an advanced-generation synthetic cultivar derived from Aurora hard fescue. Five cycles of phenotypic recurrent selection over a 10-year period after direct applications of glyphosate at 0.8 to 1.6 kg·ha⁻¹ was used to develop this cultivar (Hart et al., 2005). Further study of 'Aurora Gold' by McCullough et al. (2015) determined the mechanism of resistance to glyphosate was due the result of lower target-site inhibition. The successful establishment of fine fescues is greatly influenced by controlling weeds.

Having mesotrione-tolerant fine fescues would give turf managers an option to control problematic weeds during establishment. The objectives of this research were 1) to use a recurrent selection technique (Vogel and Pedersen, 1993) to develop mesotrione-tolerant chewings, hard, and strong creeping red fescues; and 2) to conduct field trials to compare the new selections to commercially available cultivars and experimental lines not selected for tolerance to mesotrione.

Materials and methods

FIRST GENERATION. All research for this project was conducted at the Rutgers Plant Biology Research and Extension Station in Adelphia, NJ. Soil type was a Holmdel sandy loam (fine-loamy, mixed, active Aquic Hapludults) with a pH of 6.7 and 2.2% organic matter. Plant selections were made from a spaced-plant nursery that had been sprayed with three applications of mesotrione at a rate of 4 oz/acre + 0.25% v/v nonionic surfactant (Activator 90; Loveland Products, Greeley, CO) at 4-week intervals during late Summer/early Fall 2011. Applications were made with a tractor-mounted agricultural sprayer set to deliver 30 gal/acre. Irrigation was applied only if there was no rainfall event within 3 d of application. Plants that had no bleaching injury response to those applications were noted and, the following spring, were grouped by growth habit, color, leaf texture, and flowering time into crossing blocks before anthesis. In total, 189 plants were moved in May 2013 into seven different crossing blocks: two hard

fescue, three chewings, and two strong creeping red fescue. Individual plants were harvested when seeds were mature. The harvested material was then dried and threshed, and a composite for each block was made using equal amounts of seed from each plant in the block.

Two field trials were planted to determine the herbicide effects of the first generation (G1) of selections on 9 Sept. 2013 and 18 Sept. 2014. The 2013 turf trial included a replicated section that included a composite of each crossing block, commercially available cultivars, and experimental lines that had not undergone mesotrione selection. A nonreplicated section of single plot progenies from each maternal parent of the seven crossing blocks described previously was also included. This nonreplicated section of the trial is used only for breeding and selection work and is not part of any statistical analysis because there is no replication. The unreplicated progeny plots were included in the trial to observe the performance of the progeny from each maternal parent and to make selections to tiller plant material for further selection work and for breeding subsequent generations. Plots measured 3 × 5 ft, with a 6-inch unseeded border, and were sown at a rate of 3.67 lb/1000 ft². A randomized complete block design was used with three replications. The 2014 trial was a repeat of the 2013, but only included the replicated entries. Trials were maintained at a 2.5-inch mowing height with rotary mower at a frequency to avoid excessive accumulation of clippings. Each trial received 1 lb/1000 ft² of nitrogen (N) at seeding as 10N-4.4P-8.3K and an additional 2 lb/1000 ft² N as 19N-0P-7.5K over the life of the trial (2 years) in two 0.5-lb/1000 ft² applications per year of the trial. Both trials were irrigated to prevent severe drought stress during the summer months.

Applications of mesotrione were made after sowing at a rate of 3 oz/acre + 0.25% v/v nonionic surfactant followed by an application of 2 oz/acre + 0.25% v/v nonionic surfactant 28 d after seedling emergence to the entire field trial area. Visual ratings were taken for establishment, injury through the first 12 weeks after planting, and quality for a 2-year period

after the trial was planted. Each visual rating used a 1- to 9-point scale, where 9 is the best establishment, least amount of injury, and highest turf quality, respectively. For establishment, injury, and turf quality, the minimum acceptable rating is 5. Data were subjected to analysis of variance with the General Linear Model procedure in SAS (version 9.3; SAS Institute, Cary, NC). Means were separated with Fisher's protected least significant difference (LSD) test at $\alpha = 0.05$.

SECOND GENERATION. Individual plants from the single plot progenies from the 2013 trial were selected from plots with the least mesotrione injury and best turf-quality ratings. Tillers were taken and individual plants were planted in a spaced-plant nursery and allowed to establish. In total, there were 6840 plants planted in the nursery: 3456 hard fescues, 2616 chewings fescues, and 768 strong creeping red fescues. Four applications of mesotrione at 4 oz/acre at 4-week intervals were made, followed by an application at 5 oz/acre 2 weeks after the last 4-oz/acre application made during late Summer/early Fall 2014, as described previously for the G1 field application. Bleaching injury symptoms began to appear 3 to 5 d after the last application. Plants exhibiting no bleaching injury were documented. The following spring, plants that exhibited no injury and had good turf quality traits with no disease were selected and grouped by growth habit, color, leaf texture, and flowering time, and were moved into crossing blocks before anthesis. In total, 290 plants were moved into eight individual crossing blocks: two chewings, four hard, and two strong creeping red fescues. Individual plants were harvested, dried, and threshed, and a composite for each block was made using seed from each plant in the block.

The second-generation (G2) turf trial (2015) included both a replicated section and single plot progeny as described for the 2013 trial. The turf trial was seeded 26 Aug. 2015. This trial consisted of 4- × 6-ft plots, with a 6-inch unseeded border, and were sown at a rate of 3.67 lb/1000 ft². Larger plots were used so herbicide strip treatments could be applied. The strips included a 2-ft strip of a 3-oz/

acre rate of mesotrione and a 2-ft strip of nontreated control. An example of two plots with each strip is shown in Fig. 1. Each treatment was applied at sowing and was repeated 28 d after seedling emergence with a carbon dioxide (CO₂)-pressurized sprayer calibrated to deliver 30 gal/acre. Plots were arranged in a randomized complete block design with three replications. Ratings were taken as described previously for injury and turf quality. An additional rating capturing the negative impact to establishment from the mesotrione treatment was also included. This was a comparison of the mesotrione strip to the nontreated portion of the turf plot. Ratings were made on a 1- to 9-scale, where 9 is no negative effect on establishment from mesotrione and 1 is complete inhibition of establishment. Data were subjected to analysis of variance with the General Linear Model procedure in SAS (version 9.3). Means were separated with Fisher's protected LSD test at $\alpha = 0.05$. Trial maintenance, including mowing, fertility, and irrigation, are the same as described previously for the G1 trials.

THIRD GENERATION. Selections from the single plot progeny section of the 2015 trial were made based on mesotrione-induced injury, effect of mesotrione on establishment, and overall turf quality for the following year. In total, 7692 individual selections were planted in Fall 2016: 3900 hard fescues, 2112 chewings fescues, and 1680 strong creeping red fescues. Two applications of mesotrione at a rate of 6 oz/acre + 0.25% v/v nonionic surfactant at a 2-week interval followed by an application of mesotrione at a rate of 8 oz/acre +

0.25% v/v nonionic surfactant 1 week after the previous spray. Sprays were conducted as described for G1 field applications. Increased rates of mesotrione and a shorter reapplication interval were necessary because no injury was observed after the two 6-oz/acre rate applications at a 2-week interval. Injury was recorded and plants were selected the following spring using the parameters described previously. In total, 314 plants were selected to use in 14 individual crossing blocks: five chewings fescues, five hard fescues, and four strong creeping red fescues.

The G3 selected plants were planted in a field trial seeded on 5 Sept. 2018. Plots were 3 × 5 ft, with a 6-inch unseeded border, and were sown at a rate of 3.67 lb/1000 ft². A randomized complete block design was used with three replications for the replicated entries, followed by an unreplicated section of single plot progeny of each maternal line of the crossing blocks. Replicated plots had three 1.5-ft-wide strip treatments: 1.5 ft of 4 oz/acre mesotrione + 0.25% v/v nonionic surfactant, 1.5 ft of untreated control, and 1.5 ft of 8 oz/acre mesotrione + 0.25% v/v nonionic surfactant. Each treatment was applied at sowing and at 28 d after seedling emergence with a CO₂-pressurized sprayer calibrated to deliver 30 gal/acre. Plots were rated for injury and establishment inhibition as a comparison with the untreated control section of the same plot. The rating was made based on a 1- to 9-scale, where 9 is no injury or reduction in establishment and 1 is no establishment or all bleached tissue. There were also tall fescue (*Festuca arundinacea*) and kentucky bluegrass

(*Poa pratensis*) cultivars included in our study to compare the mesotrione selected fine fescue material with species that are on the Tenacity label and considered safe to use at seeding. Ratings were taken separately for the 4- and 8-oz/acre rate strips. Data were subjected to analysis of variance with the General Linear Model procedure in SAS (version 9.3). Means were separated with Fisher's protected LSD test at $\alpha = 0.05$. Trial maintenance, including mowing, fertility, and irrigation, are the same as described for the G1 trials.

Results and discussion

G1 FIELD TRIAL. The mesotrione injury ratings for the G1 trials ranged from 5.8 to 2.0 (LSD = 1.0). Hard fescues overall exhibited the most injury to mesotrione compared with chewings and strong creeping red fescues. Both G1 mesotrione-tolerant hard fescue selections (MEH1 Composite and MEH2 Composite) were in the top statistical grouping for having the lowest injury, with ratings of 4.5 and 4.3, respectively (Table 1). Chewings fescue, as a species, exhibited the least injury to mesotrione compared with strong creeping red fescue and hard fescue. The G1 mesotrione-tolerant composites of chewings fescue (MEW1 Composite, MEW2 Composite, and MEW3 Composite) exhibited light to moderate injury, with ratings of 4.8, 5.8, and 5.0, respectively. However, 'Radar' chewings fescue also rated a 4.8 for mesotrione injury. The strong creeping red fescues were between hard and chewings fescue for mesotrione injury. The G1 mesotrione-tolerant selection composites of strong creeping red fescue (MES1 Composite and MES2 Composite) exhibited moderate injury, with ratings of 3.7 and 3.3, respectively. Each of the G1 mesotrione-tolerant selection composites had lower mesotrione injury (higher ratings) and were near the top of the ratings for each of their species group compared with experimental selections and commercial cultivars, except for strong creeping red fescue.

Establishment for the trial had a range of 5.8 to 1.4 (LSD = 1.0). The two G1 mesotrione-tolerant selection hard fescues (MEH1 Composite and MEH2 Composite) were somewhat slower to establish; therefore, the

Fig. 1. Example of mesotrione-treated strip (bottom) and a nonmesotrione-treated strip (top) in a field trial including first-, second-, and third-generation mesotrione-tolerant selections, commercially available cultivars, and experimental selections of fine fescues. Note the bleaching injury and decreasing establishment in a nonmesotrione selected fine fescue turf plot (left) and a third-generation mesotrione-tolerant selection turf plot (right) exhibiting no injury or reduction in establishment.

Table 1. Establishment and mesotrione injury ratings of first-generation mesotrione-tolerant selections, experimental selections, and commercially available cultivars of fine fescue in two field trials planted in Sept. 2013 and Sept. 2014 at the Rutgers Plant Biology Research and Extension Station in Adelphia, NJ. Mesotrione was applied at sowing (3 oz/acre + 0.25% v/v nonionic surfactant) and 28 d after seedling emergence (2 oz/acre + 0.25% v/v nonionic surfactant). Data were subjected to analysis of variance with the General Linear Model procedure in SAS (version 9.3; SAS Institute, Cary, NC). Means were separated with Fisher's protected least significant difference (LSD) test at $\alpha = 0.05$. (1 oz/acre = 70.0532 g·ha⁻¹).

Injury rank	Entry ^z	Species	Establishment (1–9 scale) ^y	Injury (1–9 scale) ^x
1	MEW2 Composite (G1)	Chewings	5.3	5.8
2	Seabreeze GT	Slender creeping	4.4	5.2
3	MEW3 Composite (G1)	Chewings	4.9	5.0
4	4-12FF-1	Strong creeping	5.8	5.0
5	MEW1 Composite (G1)	Chewings	5.2	4.8
6	Radar	Chewings	4.9	4.8
7	7W4 Composite	Chewings	4.2	4.7
8	4-12FF-2	Strong creeping	4.4	4.7
9	MEH1 Composite (G1)	Hard	2.8	4.5
10	Daisy	Sheep	2.5	4.5
11	2-10FRR-12	Strong creeping	4.2	4.5
12	2-10FRR-13	Strong creeping	4.2	4.5
13	5-12FF-5	Strong creeping	4.5	4.5
15	PPG-FRC 113	Chewings	4.0	4.3
16	PPG-FRC 115	Chewings	4.6	4.3
17	PPG-FRC 107	Chewings	4.8	4.3
14	MEH2 Composite (G1)	Hard	3.0	4.3
18	4-12FF-BULK	Strong creeping	5.2	4.3
19	4-12FF-5	Strong creeping	5.2	4.3
20	Fairmont	Chewings	4.8	4.2
23	PPG-FRC 114	Chewings	5.0	4.0
25	Shadow II	Chewings	3.9	4.0
26	SR5130	Chewings	4.4	4.0
27	08-5FCE+	Chewings	3.5	4.0
28	Ambrose	Chewings	2.8	4.0
29	7W2 Composite	Chewings	3.8	4.0
21	TE1 Composite	Hard	2.3	4.0
22	BM2 Composite	Hard	1.9	4.0
24	2-10FRR-8	Strong creeping	4.6	4.0
30	PPG-FRR 111	Strong creeping	4.5	4.0
31	4-12FF-3	Strong creeping	4.9	4.0
36	7W3 Composite	Chewings	3.6	3.8
32	H575 Composite	Hard	2.3	3.8
33	PSG TH3	Hard	3.4	3.8
34	7H3 Composite	Hard	2.4	3.8
35	TE2 Composite	Hard	1.7	3.8
37	FT6 Composite	Strong creeping	2.8	3.8
38	5-12FF-8	Strong creeping	4.4	3.8
39	FF2	Strong creeping	4.3	3.8
40	4GRP	Strong creeping	3.5	3.8
47	Compass	Chewings	4.9	3.7
41	H573 Composite	Hard	2.3	3.7
42	Reliant IV	Hard	2.3	3.7
43	7H1 Composite	Hard	2.8	3.7
44	PPG-FL 107	Hard	2.8	3.7
49	Seafire	Slender creeping	3.0	3.7
45	MES1 Composite (G1)	Strong creeping	3.2	3.7
46	Navigator II	Strong creeping	4.4	3.7
48	CRF-11-4A	Strong creeping	4.2	3.7
50	Shademaster III	Strong creeping	3.2	3.7
51	5-12FF-4	Strong creeping	2.7	3.7
54	4SHR-CH	Chewings	4.5	3.5
52	Predator	Hard	1.9	3.5
53	Cardinal	Strong creeping	4.1	3.5

(Continued on next page)

Table 1. (*Continued*) Establishment and mesotrione injury ratings of first-generation mesotrione-tolerant selections, experimental selections, and commercially available cultivars of fine fescue in two field trials planted in Sept. 2013 and Sept. 2014 at the Rutgers Plant Biology Research and Extension Station in Adelphia, NJ. Mesotrione was applied at sowing (3 oz/acre + 0.25% v/v nonionic surfactant) and 28 d after seedling emergence (2 oz/acre + 0.25% v/v nonionic surfactant). Data were subjected to analysis of variance with the General Linear Model procedure in SAS (version 9.3; SAS Institute, Cary, NC). Means were separated with Fisher's protected least significant difference (LSD) test at $\alpha = 0.05$. (1 oz/acre = 70.0532 g·ha⁻¹).

Injury rank	Entry ^z	Species	Establishment (1–9 scale) ^y	Injury (1–9 scale) ^x
55	FT2 Composite	Strong creeping	3.0	3.5
56	Kent	Strong creeping	4.3	3.5
58	7W1 Composite	Chewings	3.9	3.3
57	PPG-FL 106	Hard	2.4	3.3
59	7C3 Composite	Strong creeping	3.3	3.3
60	2-10FRRBULK	Strong creeping	4.1	3.3
61	MES2 Composite (G1)	Strong creeping	3.6	3.3
62	SR5250	Strong creeping	4.0	3.3
63	OR 126	Strong creeping	3.8	3.3
64	PPG-FRR 103	Strong creeping	4.4	3.3
65	FT1 Composite	Strong creeping	3.1	3.3
66	PSG 5RM	Strong creeping	2.9	3.3
67	BRSO	Strong creeping	4.3	3.3
68	5-12FF-6	Strong creeping	3.8	3.3
69	BRSG	Strong creeping	4.1	3.3
70	5-12FF-BULK	Strong creeping	3.6	3.3
82	PSG 50C3	Chewings	1.7	3.2
85	Windward	Chewings	3.6	3.2
71	7H4 Composite	Hard	3.1	3.2
72	PPG-FL 108	Hard	3.7	3.2
73	H571 Composite	Hard	2.2	3.2
74	7H2 Composite	Hard	1.8	3.2
76	7H6 Composite	Hard	3.1	3.2
77	Soilguard	Hard	1.9	3.2
75	Marco Polo	Sheep	3.8	3.2
80	Sealink	Slender creeping	3.7	3.2
78	2-10FRR-6	Strong creeping	4.3	3.2
79	S571 Composite	Strong creeping	3.4	3.2
81	Jasper II	Strong creeping	4.2	3.2
83	FT5 Composite	Strong creeping	3.0	3.2
84	Gibraltar Gold	Strong creeping	3.4	3.2
86	4CRD-8	Strong creeping	3.5	3.2
87	Oracle	Strong creeping	2.8	3.2
91	4CHY	Chewings	3.6	3.0
89	Oxford	Hard	1.4	3.0
88	Blueray	Blue hard	2.4	3.0
90	2-10FRR-4	Strong creeping	4.2	3.0
92	FT3 Composite	Strong creeping	2.5	3.0
93	4CRD-P	Strong creeping	3.5	3.0
94	Beacon	Hard	3.0	2.8
95	Spartan II	Hard	3.5	2.8
96	FRR 62	Strong creeping	2.8	2.8
97	Gibraltar	Strong creeping	3.6	2.8
98	FT4 Composite	Strong creeping	2.5	2.7
99	Miser	Strong creeping	2.3	2.5
100	4BND	Hard	3.4	2.3
101	Bighorn GT	Hard	1.9	2.3
102	Azure	Hard	1.8	2.0
		LSD ($\alpha = 0.05$)	1.0	1.0

^zG1 in parentheses indicates first-generation mesotrione-tolerant selection.

^y1 = no establishment of seedlings (i.e., bare soil), 5 = minimum acceptable rating, and 9 = fully established turfgrass.

^x1 = completely bleached tissue, 5 = minimum acceptable injury rating, and 9 = no injury.

Table 2. Overall, year 1 and year 2 turfgrass quality ratings of first-generation mesotrione-tolerant selections, experimental selections, and commercially available cultivars of fine fescue in two field trials planted in 2013 and 2014 at the Rutgers Plant Biology Research and Extension Station in Adelphia, NJ. Mesotrione was applied at sowing (3 oz/acre + 0.25% v/v nonionic surfactant) and 28 d after seedling emergence (2 oz/acre + 0.25% v/v nonionic surfactant). Data were subjected to analysis of variance with the General Linear Model procedure in SAS (version 9.3; SAS Institute, Cary, NC). Means were separated with Fisher's protected least significant difference (LSD) test at $\alpha = 0.05$. (1 oz/acre = 70.0532 g·ha⁻¹).

Quality rank	Entry ^z	Species	Quality (1–9 scale) ^y		
			Overall	Yr 1	Yr 2
1	PSG TH3	Hard	5.7	5.5	5.9
2	H575 Composite	Hard	5.5	5.1	6.1
3	MEH1 Composite (G1)	Hard	5.5	5.4	5.6
4	PPG-FL 108	Hard	5.5	5.3	5.7
5	MEH2 Composite (G1)	Hard	5.4	5.3	5.6
6	7H1 Composite	Hard	5.4	5.3	5.6
7	BM2 Composite	Hard	5.4	5.2	5.7
8	7H4 Composite	Hard	5.3	4.9	5.8
9	TE1 Composite	Hard	5.3	4.9	5.8
10	7H3 Composite	Hard	5.3	4.9	5.8
11	4BND	Hard	5.3	4.9	5.7
12	H573 Composite	Hard	5.2	4.7	5.8
13	PPG-FL 107	Hard	5.2	4.9	5.5
14	Reliant IV	Hard	5.2	4.8	5.7
15	MEW1 Composite (G1)	Chewings	5.2	5.8	4.4
16	PPG-FL 106	Hard	5.2	4.7	5.8
17	TE2 Composite	Hard	5.1	4.7	5.7
18	Marco Polo	Sheep	5.1	5.1	5.2
19	Beacon	Hard	5.1	4.6	5.7
20	Spartan II	Hard	5.1	4.8	5.5
21	Blueray	Blue hard	5.1	4.7	5.5
22	7H2 Composite	Hard	5.0	4.6	5.6
23	MEW2 Composite (G1)	Chewings	5.0	5.5	4.4
24	Predator	Hard	5.0	4.4	5.7
25	H571 Composite	Hard	4.9	4.3	5.6
26	MEW3 Composite (G1)	Chewings	4.9	5.2	4.4
27	Radar	Chewings	4.8	5.2	4.4
28	7H6 Composite	Hard	4.8	4.6	5.1
29	Soilguard	Hard	4.6	4.2	5.0
30	Oxford	Hard	4.6	4.0	5.3
31	Bighorn GT	Hard	4.6	4.3	5.0
32	PPG-FRC 114	Chewings	4.5	4.8	4.3
33	PPG-FRC 115	Chewings	4.5	4.8	4.2
34	7W3 Composite	Chewings	4.5	4.7	4.2
35	7W1 Composite	Chewings	4.5	4.7	4.1
36	Fairmont	Chewings	4.4	4.7	4.2
37	PPG-FRC 113	Chewings	4.4	4.5	4.3
38	PPG-FRC 107	Chewings	4.4	4.8	4.0
39	7W4 Composite	Chewings	4.3	4.8	3.8
40	Shadow II	Chewings	4.3	4.5	4.2
41	SR5130	Chewings	4.2	4.4	4.1
42	Sealink	Slender creeping	4.2	4.7	3.7
43	2-10FRR-8	Strong creeping	4.2	4.2	4.2
44	Seabreeze GT	Slender creeping	4.1	4.6	3.5
45	08-5FCE+	Chewings	4.0	4.2	3.8
46	Compass	Chewings	4.0	4.4	3.7
47	Daisy	Sheep	4.0	3.8	4.3
48	Ambrose	Chewings	4.0	4.2	3.8
49	7W2 Composite	Chewings	4.0	4.3	3.6
50	4SHR-CH	Chewings	4.0	4.3	3.7
51	MES1 Composite (G1)	Strong creeping	4.0	3.8	4.2
52	2-10FRRBulk	Strong creeping	4.0	4.0	3.9
53	2-10FRR-6	Strong creeping	3.9	3.8	4.2

(Continued on next page)

Table 2. (*Continued*) Overall, year 1 and year 2 turfgrass quality ratings of first-generation mesotrione-tolerant selections, experimental selections, and commercially available cultivars of fine fescue in two field trials planted in 2013 and 2014 at the Rutgers Plant Biology Research and Extension Station in Adelphia, NJ. Mesotrione was applied at sowing (3 oz/acre + 0.25% v/v nonionic surfactant) and 28 d after seedling emergence (2 oz/acre + 0.25% v/v nonionic surfactant). Data were subjected to analysis of variance with the General Linear Model procedure in SAS (version 9.3; SAS Institute, Cary, NC). Means were separated with Fisher's protected least significant difference (LSD) test at $\alpha = 0.05$. (1 oz/acre = 70.0532 g·ha⁻¹).

Quality rank	Entry ^z	Species	Quality (1–9 scale) ^y		
			Overall	Yr 1	Yr 2
54	4CHY	Chewings	3.9	4.2	3.7
55	MES2 Composite (G1)	Strong creeping	3.8	3.8	3.9
56	Azure	Hard	3.8	3.5	4.2
57	2-10FRR-12	Strong creeping	3.8	3.7	3.9
58	2-10FRR-4	Strong creeping	3.8	3.7	4.0
59	S571 Composite	Strong creeping	3.8	3.7	3.9
60	Navigator II	Strong creeping	3.8	3.8	3.7
61	SR5250	Strong creeping	3.7	3.7	3.8
62	7C3 Composite	Strong creeping	3.7	3.5	3.9
63	2-10FRR-13	Strong creeping	3.7	3.7	3.8
64	PPG-FRR 111	Strong creeping	3.7	3.8	3.6
65	Cardinal	Strong creeping	3.7	3.7	3.7
66	Jasper II	Strong creeping	3.7	3.7	3.7
67	Seafire	Slender creeping	3.7	3.9	3.4
68	OR 126	Strong creeping	3.7	3.7	3.6
69	CRF-11-4A	Strong creeping	3.6	3.7	3.4
70	PPG-FRR 103	Strong creeping	3.6	3.6	3.5
71	4-12FF-Bulk	Strong creeping	3.5	3.9	3.2
72	FRR 62	Strong creeping	3.5	3.4	3.7
73	PSG 50C3	Chewings	3.5	3.4	3.6
74	Windward	Chewings	3.4	3.6	3.3
75	Kent	Strong creeping	3.4	3.6	3.2
76	FT5 Composite	Strong creeping	3.4	3.3	3.6
77	4-12FF-3	Strong creeping	3.4	3.7	3.1
78	5-12FF-8	Strong creeping	3.4	3.6	3.2
79	Shademaster III	Strong creeping	3.4	3.4	3.4
80	FT2 Composite	Strong creeping	3.4	3.4	3.5
81	BRSG	Strong creeping	3.4	3.6	3.2
82	BRSO	Strong creeping	3.4	3.5	3.3
83	Gibraltar	Strong creeping	3.4	3.4	3.3
84	FF2	Strong creeping	3.3	3.5	3.2
85	PSG 5RM	Strong creeping	3.3	3.3	3.4
86	4-12FF-1	Strong creeping	3.3	3.6	3.0
87	FT6 Composite	Strong creeping	3.3	3.2	3.5
88	FT4 Composite	Strong creeping	3.3	3.2	3.5
89	Miser	Strong creeping	3.3	3.2	3.5
90	FT3 Composite	Strong creeping	3.3	3.0	3.6
91	4-12FF-2	Strong creeping	3.3	3.6	2.9
92	4-12FF-5	Strong creeping	3.3	3.6	2.9
93	Gibraltar Gold	Strong creeping	3.2	3.2	3.3
94	4CRD-8	Strong creeping	3.2	3.3	3.1
95	4CRD-P	Strong creeping	3.2	3.2	3.3
96	5-12FF-6	Strong creeping	3.2	3.1	3.3
97	FT1 Composite	Strong creeping	3.2	3.0	3.4
98	5-12FF-5	Strong creeping	3.2	3.4	2.9
99	Oracle	Strong creeping	3.0	3.0	3.0
100	4GRP	Strong creeping	3.0	3.0	3.0
101	5-12FF-Bulk	Strong creeping	3.0	2.9	3.1
102	5-12FF-4	Strong creeping	2.4	2.2	2.8
103	7 Seas	Chewings	1.4	1.3	1.5
		LSD ($\alpha = 0.05$)	0.5	0.7	0.5

^zG1 in parentheses indicates first-generation mesotrione-tolerant selection.

^y1 = lowest quality, 5 = minimum acceptable rating, and 9 = best turfgrass quality.

Table 3. The effect of mesotrione on the establishment and injury ratings of first- and second-generation mesotrione-tolerant selections, experimental selections, and commercially available cultivars of fine fescue in a field trial planted in 2015 at the Rutgers Plant Biology Research and Extension Station in Adelphia, NJ. Mesotrione was applied at 3 oz/acre at sowing and 28 d after seedling emergence + 0.25% v/v nonionic surfactant. Data were subjected to analysis of variance with the General Linear Model procedure in SAS (version 9.3; SAS Institute, Cary, NC). Means were separated with Fisher's protected least significant difference (LSD) test at $\alpha = 0.05$. (1 oz/acre = 70.0532 g·ha⁻¹).

Injury rank	Entry ^z	Species	Establishment (1–9 scale) ^y	Injury (1–9 scale) ^x
1	TEH2 Composite (G2)	Hard	8.0	8.2
2	TEH4 Composite (G2)	Hard	7.3	8.2
3	TEH3 Composite (G2)	Hard	7.7	8.0
4	TEH1 Composite (G2)	Hard	7.7	7.8
5	TW2 Composite (G2)	Chewings	7.0	7.7
6	Minimus	Hard	5.7	7.2
7	TW1 Composite (G2)	Chewings	5.3	7.0
8	MEH1 Composite (G1)	Hard	6.3	6.2
9	Chariot	Hard	5.3	6.2
10	Firefly	Hard	4.0	6.2
11	MEW1 Composite (G1)	Chewings	7.0	6.2
12	Sword	Hard	5.0	6.0
13	TR1 Composite (G2)	Strong creeping	6.0	6.0
14	MEH2 Composite (G1)	Hard	6.0	5.5
15	FH2 Composite	Hard	4.7	5.3
16	FH3 Composite	Hard	5.3	5.3
17	Beacon	Hard	4.0	5.3
18	Radar	Chewings	5.0	5.3
19	MEW2 Composite (G1)	Chewings	7.3	5.0
20	FH4 Composite	Hard	4.7	4.8
21	PPG-FRC 113	Chewings	4.7	4.8
22	Compass	Chewings	4.3	4.7
23	Blueray	Blue hard	4.3	4.3
24	TR2 Composite (G2)	Strong creeping	5.0	4.3
25	FW2 Composite	Chewings	4.7	4.2
26	FR3 Composite	Strong creeping	4.0	4.2
27	FH1 Composite	Hard	3.7	4.0
28	Blue Hornet	Sheep	3.0	3.2
29	Ambrose	Chewings	2.3	3.2
30	Marvel	Strong creeping	3.0	3.2
31	Lighthouse	Slender creeping	3.0	3.0
32	PPG-FRT 101	Slender creeping	3.7	3.0
33	PPG-FRR 111	Strong creeping	3.0	3.0
34	Garnet	Strong creeping	2.3	2.8
35	FR1 Composite	Strong creeping	2.3	2.5
36	FR2 Composite	Strong creeping	2.0	2.5
37	Navigator II	Strong creeping	2.3	2.5
38	Pathfinder	Strong creeping	2.7	2.5
39	FR4 Composite	Strong creeping	2.3	2.3
40	Cardinal	Strong creeping	2.7	2.3
41	MES2 Composite (G1)	Strong creeping	3.3	2.0
42	SR5250	Strong creeping	1.7	1.8
43	Predator	Hard	2.3	1.5
44	PPG-FL 106	Hard	2.0	1.3
45	Audubon	Strong creeping	1.3	1.2
46	Reliant IV	Hard	1.7	1.0
47	Rescue 911	Hard	1.3	1.0
48	Azure	Hard	1.3	1.0
		LSD ($\alpha = 0.05$)	1.0	2.1

^zG1 or G2 in parentheses indicates first- or second-generation mesotrione-tolerant selection, respectively.

^yMesotrione effects on establishment compared with untreated, where 1 = complete inhibition of establishment, 5 = minimum acceptable rating, and 9 = no reduction in establishment.

^xInjury on a 1- to 9-point scale, with 1 = completely bleached tissue, 5 = minimum acceptable rating, and 9 = no injury.

Table 4. Turf quality ratings of mesotrione-treated strip (3 oz/acre + 0.25% v/v nonionic surfactant applications at sowing and 28 d after seedling emergence) and untreated strip of first- and second-generation mesotrione-tolerant selections, commercially available cultivars, and experimental selections of fine fescues in a field trial planted in Sept. 2015 at the Rutgers Plant Biology Research and Extension Station in Adelphia, NJ. Data were subjected to analysis of variance with the General Linear Model procedure in SAS (version 9.3; SAS Institute, Cary, NC). Means were separated with Fisher's protected least significant difference (LSD) test at $\alpha = 0.05$. (1 oz/acre = 70.0532 g·ha⁻¹).

Injury rank	Entry ^z	Species	Quality (1–9 scale) ^y		
			2016 Mesotrione	2016 Untreated	2017 ^x
1	TEH2 Composite (G2)	Hard	5.7	5.6	6.3
2	TEH4 Composite (G2)	Hard	5.8	5.7	6.4
3	TEH3 Composite (G2)	Hard	5.9	5.8	6.5
4	TEH1 Composite (G2)	Hard	6.0	5.9	6.1
5	TW2 Composite (G2)	Chewings	5.2	5.2	4.8
6	Minimus	Hard	5.0	5.0	5.0
7	TW1 Composite (G2)	Chewings	5.2	5.1	4.6
8	MEH1 Composite (G1)	Hard	5.5	5.4	5.4
9	Chariot	Hard	5.1	5.0	5.2
10	Firefly	Hard	4.7	4.7	5.4
11	MEW1 Composite (G1)	Chewings	5.5	5.4	4.8
12	Sword	Hard	4.9	4.9	5.0
13	TR1 Composite (G2)	strong creeping	5.0	4.9	3.7
14	MEH2 Composite (G1)	Hard	5.7	5.9	6.3
15	FH2 Composite	Hard	4.8	5.0	5.8
16	FH3 Composite	Hard	4.5	4.8	5.3
17	Beacon	Hard	4.9	5.0	5.3
18	Radar	Chewings	4.7	4.6	4.4
19	MEW2 Composite (G1)	Chewings	5.3	5.1	4.5
20	FH4 Composite	Hard	5.3	5.2	6.1
21	PPG-FRC 113	Chewings	5.0	4.9	4.8
22	Compass	Chewings	4.1	4.1	3.6
23	Blueray	Blue hard	4.0	4.1	3.9
24	TR2 Composite (G2)	Strong creeping	5.5	5.4	4.1
25	FW2 Composite	Chewings	5.5	5.4	5.0
26	FR3 Composite	Strong creeping	4.7	4.8	4.4
27	FH1 Composite	Hard	5.3	5.4	6.6
28	Blue Hornet	Sheep	3.2	3.3	3.6
29	Ambrose	Chewings	4.1	4.2	3.7
30	Marvel	Strong creeping	3.6	3.9	3.1
31	Lighthouse	slender creeping	2.7	2.6	2.6
32	PPG-FRT 101	slender creeping	4.8	5.0	5.0
33	PPG-FRR 111	Strong creeping	4.3	4.2	3.8
34	Garnet	Strong creeping	2.6	3.4	3.0
35	FR1 Composite	Strong creeping	4.1	4.4	4.8
36	FR2 Composite	Strong creeping	4.4	4.9	4.7
37	Navigator II	Strong creeping	3.4	4.0	3.3
38	Pathfinder	Strong creeping	3.1	3.4	3.1
39	FR4 Composite	Strong creeping	4.6	4.8	4.8
40	Cardinal	Strong creeping	3.4	3.7	3.2
41	MES2 Composite (G1)	Strong creeping	4.8	5.2	3.7
42	SR5250	Strong creeping	2.5	3.2	2.9
43	Predator	Hard	3.8	4.1	5.2
44	PPG-FL 106	Hard	2.6	3.5	4.6
45	Audubon	Strong creeping	2.0	3.3	3.3
46	Reliant IV	Hard	3.4	3.9	5.5
47	Rescue 911	Hard	2.0	2.3	3.1
48	Azure	Hard	2.0	2.7	3.5
		LSD ($\alpha = 0.05$)	1.1	0.9	0.9

^zG1 or G2 in parentheses indicates first- or second-generation mesotrione-tolerant selection, respectively.

^yQuality rated on a 1- to 9-point scale, with 1 = lowest quality, 5 = minimum acceptable rating, and 9 = best turfgrass quality.

^xPlots had no effect from herbicide application so the entire plot was rated for turf quality.

establishment ratings were relatively poor, with ratings of 2.8 and 3.0, respectively. The three G1 mesotrione-tolerant selections of chewings fescues (MEW1 Composite, MEW2 Composite, and MEW3 Composite) had good establishment overall, with ratings of 5.2, 5.3, and 4.9, respectively. The G1 mesotrione-tolerant selections of strong creeping red fescues (MES1 Composite and MES2 Composite) had establishment ratings of 3.2 and 3.6, respectively. The strong creeping red fescues were slower to establish compared with other fine fescue field trials conducted at the Adelphia farm for those years that were not treated with mesotrione, and it was suspected that the mesotrione applications could have been a factor.

Turf quality was analyzed for each year (year 1 and year 2) and overall for both years (Table 2). Entries that were poor to establish in general had poor turf quality ratings for year 1, but some of those had much better year 2 turf quality, which indicates there could have been lasting effects from the mesotrione treatments that never allowed the grasses to establish fully. Having treated and untreated sections of each plot would allow one to observe more comprehensively the effects of the herbicide compared with the genetics of each cultivar in the next-generation field trial. Overall, the G1 mesotrione-tolerant selections had acceptable turf quality or a turf quality rating that was better than the species average.

G2 FIELD TRIAL. Overall, the performance of the G2 mesotrione-tolerant selections were better than the G1 within each species. The four G2 mesotrione-tolerant selections of hard fescue (TEH4 Composite, TEH2 Composite, TEH3 Composite, and TEH1 Composite) were the least injured in the trial, with ratings of 8.2, 8.2, 8.0, and 7.8, respectively (Table 3). The mesotrione-tolerant selections of chewings fescue (TW2 Composite and TW1 Composite) had very little injury, with ratings of 7.7 and 7.0, respectively, compared with the G1 MEW1 Composite and MEW2 Composite, which rated 6.2 and 5.0, respectively. All the G2 hard and chewings selections were in the top statistical grouping for injury. The G2 mesotrione-tolerant selections of strong creeping red fescues (TR1 Composite and TR2 Composite)

were not in the top statistical group, but only had moderate injury (6.0 and 4.3) and were better than the G1 strong creeping red fescue MES2 Composite, which rated a 4.0.

Establishment ratings ranged from 8.0 to 1.3 (LSD = 1.0) (Table 3). The G2 mesotrione-tolerant selections of hard fescue (TEH2 Composite, TEH3 Composite, TEH1 Composite, and TEH4 Composite) were least affected by mesotrione at establishment and were the top rated, with ratings of 8.0, 7.7, 7.7, and 7.3, respectively. This was significantly greater than the G1 hard fescues, which had ratings of 6.3 and 6.0. The G2 mesotrione-tolerant chewings selections were affected minimally by mesotrione at establishment and had better establishment than the two G1 chewings fescue composites. The G2 strong creeping red fescues had much better establishment compared with G1: TR1 Composite rating of 6.0 and TR2 Composite rating of 5.0 compared with the G1 MES2 Composite rating of 3.3.

Turf quality was affected by the mesotrione applications in some of the more sensitive entries, so ratings were taken for both the control strips and the mesotrione-treated strips separately for year 1. Turf quality for the year 1 nonmesotrione-treated control ranged from 2.3 to 5.9, with an LSD of 0.9 (Table 4). For the mesotrione-treated strip, turf quality ranged from 2.0 to 6.0, with an LSD of 1.1. The mesotrione-tolerant selections from the G2 and G1 entries all maintained acceptable turf quality ratings, with all the G2 entries being in the top statistical group, excluding TR1 Composite, which was just 0.1 less than the cutoff for top statistical grouping.

By year 2, there were no visual effects from the mesotrione treatments, so entire plots were rated for turf quality (Table 4). The turf quality ratings for year 2 of the trial ranged from 2.6 to 6.6, with an LSD of 0.9. The top statistical grouping for year 2 turf quality ratings included all four G2 mesotrione-tolerant selection hard fescues and the MEH2 Composite from the G1 entries. Progress was made in increasing the tolerance to mesotrione from G1 to G2 while maintaining and, in many cases, improving the turfgrass quality.

G3 FIELD TRIAL. The range of injury and establishment ratings for

the 4-oz/acre rate was 1.4 to 9.0, with an LSD of 0.9 (Table 5). The top statistical grouping for the 4-oz/acre rate included all the G3 mesotrione-tolerant selections for all three species. The HTB5 Composite (hard fescue) was the best-performing entry in the trial for injury and establishment. For the 8-oz/acre rate, the rating ranged from 1.0 to 8.3, with an LSD of 1.3. The top statistical grouping of the 8-oz/acre rate included all the G3 hard fescues, all the G3 chewings fescues, and the G3 strong creeping red fescue STB1 Composite, which ranked fifth overall in each rating. This was interesting and exciting to see because, from G1 to G2, the strong creeping red fescues had the least amount of improvement.

Plants from the G1 progeny were selected to determine whether absorption and translocation were associated with bleaching injury. Studies were conducted using foliar and root uptake of carbon 14 radiolabeled isotope (^{14}C) mesotrione along with a rate titration of three lines each of chewings fescue, hard fescue, and strong creeping red fescue (Tate et al., 2019). Translocation of foliar-absorbed ^{14}C mesotrione was not associated with differential tolerance levels of the three species. There were differences among lines within species for root absorption, but it was comparable among the three species. This suggests factors other than absorption and translocation are what is being selected for in recurrent breeding, and further studies are needed to determine the mechanism for increased tolerance.

Conclusions

These results demonstrate that using a recurrent selection method is an effective way to increase the tolerance of fine fescues to mesotrione herbicide. After three generations, selections of hard, chewings, and strong creeping red fescues had equivalent or better tolerance to mesotrione than tall fescues and kentucky bluegrasses, which are on the label for safe use at seeding. These G3 selections will continue to be tested for their turf quality performance and to ensure there are not any long-term adverse effects of mesotrione on these species. If they continue to do well in testing, the G3 fine fescues could be treated safely with mesotrione at seeding in the future to establish

Table 5. Injury ratings at two rates of mesotrione-treated first-, second-, and third-generation mesotrione-tolerant selections, experimental selections, and commercially available cultivars of fine fescues, tall fescues, and kentucky bluegrasses in a field trial planted in Sept. 2018 at the Rutgers Plant Biology Research and Extension Station in Adelphia, NJ. Mesotrione was applied at 4- and 8-oz/acre rates + 0.25% v/v nonionic surfactant at sowing and 28 d after seedling emergence. Data were subjected to analysis of variance with the General Linear Model procedure in SAS (version 9.3; SAS Institute, Cary, NC). Means were separated with Fisher's protected least significant difference (LSD) test at $\alpha = 0.05$. (1 oz/acre = 70.0532 g·ha⁻¹).

Injury rank	Cultivar ^z	Species	Injury (1–9 scale) ^y	
			0.25 lb/acre	0.5 lb/acre
1	HTB5 Composite (G3)	Hard	9.0	8.3
2	HTB4 Composite (G3)	Hard	8.9	8.3
3	TEH3 Composite (G2)	Hard	8.9	8.3
4	TEH2 Composite (G2)	Hard	9.0	8.1
5	STB1 Composite (G3)	Strong creeping	8.8	8.1
6	WTBT1 Composite (G3)	Chewings	8.9	7.9
7	WTB2 Composite (G3)	Chewings	8.9	7.9
8	Padre II	Tall fescue	8.5	7.9
9	WTBT3 Composite (G3)	Chewings	8.9	7.7
10	WTU5 Composite (G3)	Chewings	8.9	7.7
11	Talladega	Tall fescue	8.3	7.6
12	Bordeaux	Kentucky bluegrass	8.3	7.5
13	HTN3 Composite (G3)	Hard	8.9	7.5
14	STU2 Composite (G3)	Strong creeping	8.5	7.5
15	HTB2 Composite (G3)	Hard	8.7	7.4
16	WTB4 Composite (G3)	Chewings	8.6	7.3
17	Champagne	Kentucky bluegrass	8.1	7.1
18	HTB1 Composite (G3)	Hard	8.7	7.1
19	Gladiator	Hard	8.7	7.0
20	Hot Rod	Tall fescue	8.5	7.0
21	TW2 Composite (G2)	Chewings	8.3	6.9
22	Sword	Hard	8.3	6.7
23	STB3 Composite (G3)	Strong creeping	8.3	6.7
24	TR1 Composite (G2)	Strong creeping	7.9	6.7
25	STN4 Composite (G3)	Strong creeping	8.5	6.6
26	Blue Note	Kentucky bluegrass	7.5	6.5
27	Windward	Chewings	8.0	6.5
28	Ambrose	Chewings	8.1	6.3
29	Marvel	Strong creeping	7.3	5.5
30	MEW1 Composite (G1)	Chewings	6.9	4.4
31	Fairmont	Chewings	7.6	4.3
32	Navigator II	Strong creeping	6.8	4.2
33	MEH2 Composite (G1)	Hard	5.1	3.3
34	MEH1 Composite (G1)	Hard	5.5	2.5
35	SR5250	Strong creeping	2.6	1.3
36	Garnet	Strong creeping	1.4	1.0
LSD ($\alpha = 0.05$)			0.9	1.3

^zG1, G2, or G3 in parentheses indicates first-, second-, or third-generation mesotrione-tolerant selection, respectively.

^y1 = major reduction in establishment (i.e., bare soil) and completely bleached tissue, 5 = minimum acceptable rating, and 9 = no injury or reduction in establishment.

low-maintenance turf that is free from weed competition during establishment. This research helps solve a critical need in the industry and should increase the use of fine fescues in the industry by providing a tool to help establish these grasses while controlling problematic weeds such as annual bluegrass and other broadleaf weeds. Using mesotrione does not complicate or reduce the control options for these fine fescues because there are still many effective herbicides and classes of herbicides that still provide effective control. Future

research is planned to determine whether mesotrione can be used safely for weed control for seed production. If that research shows positive results, and a special use label is granted, then it would give seed farmers of these grasses another tool for weed control as well.

Literature cited

Askew, S.D. and J.B. Beam. 2002. Weed management in cool-season turf with mesotrione. *Proc. Northeast Weed Sci. Soc.* 56:129.

Beard, J.B. 1973. *Turfgrass: Science and culture*. Prentice Hall, Englewood Cliffs, NJ.

Grande, J. 2004. Seeding your lawn. Rutgers Coop. Res. Ext. fact sheet FS584.

Hanson, A.A., F.V. Juska, and G.W. Burton. 1969. Species and varieties, p. 370–409. In: A.A. Hanson and F.V. Juska (eds.). *Turfgrass science*. American Society of Agronomy, Madison, WI.

Hart, S.E., J.F. Derr, D.W. Lycan, C. Rose-Fricker, and W.A. Meyer. 2005. Increased glyphosate tolerance in 'Aurora

- Gold' hard fescue (*Festuca longifolia*). Weed Technol. 19:640–646, doi: 10.1614/WT-04-200R.1.
- Hart, S.E., P. McCullough, and C.J. Mansue. 2007. Use of mesotrione herbicide for weed control at cool-season turfgrass establishment. Ctr. Turfgrass Sci. Proc. 35–36.
- Johnston, D.T. and J.S. Faulkner. 1986. Countess and Duchess: Aminotriazole-tolerant cultivars of chewings fescue and browntop bent. J. Sports Turf Res. Inst. 62:217.
- Kaminski, J.E. and P.H. Dernoeden. 2007. Seasonal *Poa annua* L. seedling emergence patterns in Maryland. Crop Sci. 47:775–779, doi: 10.2135/cropsci2006.03.0191.
- McCullough, P.E., J. Yu, D.G. Shilling, and M.A. Czarnota. 2015. Physiological basis for glyphosate tolerance in hard fescue and perennial ryegrass cultivars. Crop Sci. 55:2352–2358, doi: 10.2135/cropsci2015.01.0035.
- Meyer, W.A. and C.R. Funk. 1989. Progress and benefits to humanity from breeding cool-season grasses for turf, p. 31–48. In: D.A. Sleper, K.H. Asay, and J.F. Pedersen (eds.). Contributions from breeding forage and turf grasses. Crop Science Society of America, Madison, WI.
- Musser, H.B. and A.T. Perkins. 1969. Guide to seedbed preparation, p. 462–473. In: A.A. Hanson and F.V. Juska (eds.). Turfgrass science. American Society of Agronomy, Madison, WI.
- Pavlick, L.E. 1985. A new taxonomic survey of the *Festuca rubra* complex in northwestern North America, with emphasis on British Columbia. Phytologia 57:1–17.
- Ruemmele, B.A., J.K. Wipff, L. Brilman, and K.W. Hignight. 2003. Fine-leaved *Festuca* species, p. 129–174. In: M.D. Cassler and R.R. Duncan (eds.). Turfgrass biology, genetics, and breeding. Wiley, Hoboken, NJ.
- Syngenta Crop Protection. 2008. Tenacity® product label. Syngenta Corp Protection, Greensboro, NC.
- Tate, T.M., W.A. Meyer, P.E. McCullough, and J. Yu. 2019. Evaluation of mesotrione tolerance levels and [14C] mesotrione absorption and translocation in three fine fescue species. Weed Sci. 67:497–503, doi: 10.1017/wsc.2019.39.
- Turgeon, A. 1996. Turfgrass management. Prentice Hall, Upper Saddle River, NJ.
- Vogel, K. and J.F. Pedersen. 1993. Breeding systems for cross-pollinated perennial grasses. Plant Breed. Rev. 11:251–274.
- Williams, M.W., W.J. Johnston, J.P. Yenish, E.D. Miltner, and C.T. Golob. 2009. Glasshouse evaluation of pre-plant and at planting applications of mesotrione on perennial ryegrass and chewings fescue. Intl. Turfgrass Soc. Res. J. 11(part 2):1237–1245.
- Willis, J.B., J.B. Beam, W.L. Barker, and S.D. Askew. 2006. Weed control options in spring-seeded tall fescue (*Festuca arundinacea*). Weed Technol. 4:1040–1046, doi: 10.1614/WT-05-138.1.