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Ground ivy (*Glechoma hederacea*) control with boron and iron in Kentucky bluegrass turf

Naba R. Amgain[1] | **Leslie L. Beck**[2] | **Aaron J. Patton**[1]

[1]Department of Horticulture and Landscape Architecture, Purdue University, West Lafayette, Indiana, USA

[2]Department of Extension Plant Sciences, New Mexico State University, Las Cruces, New Mexico, USA

Correspondence
Naba R. Amgain, Department of Horticulture and Landscape Architecture, Purdue University, West Lafayette, IN 47907, USA.
Email: namgain@purdue.edu

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Abstract

Ground ivy (*Glechoma hederacea* L.) is a perennial broadleaf weed in the mint family (*Lamiaceae*) that is commonly found in turf in the temperate climates of the United States. Cultural practices that maintain dense turf are the best way to reduce weeds; however, cultural control methods alone cannot provide complete weed control. Herbicides are commonly used to control weeds in the turfgrass industry, but interest in alternative control methods is increasing. Applications of iron-based products are an alternative chemical weed control option in turfgrass systems, but other micronutrients, such as boron, may also be a viable option. The objective of this study was to compare the efficacy of a chelated iron product as well as different boron-based products for ground ivy control and also determine if these products injure Kentucky bluegrass (*Poa pratensis* L.). The products evaluated included borax, boric acid, Solubor (disodium octaborate tetrahydrate), and Fiesta (FeHEDTA) with a low and high rate tested for each. Ground ivy cover was reduced 77% or more from a single October application of all boron sources at the high rates and the high rate of Fiesta when evaluated 9 months later. The high rate of all boron-containing products caused unacceptable turfgrass injury (<7) and reduced turf quality below acceptable levels (<6). No turfgrass injury or reduction in turf quality was observed in the Fiesta-treated plots. These results indicate that applications of the micronutrient boron can be used to control ground ivy, but not without causing injury to Kentucky bluegrass.

1 | INTRODUCTION

Ground ivy is a perennial broadleaf weed of turf in temperate climates of the United States. It is notoriously difficult to control in turfgrass systems and is also known as "creeping Charlie" by many consumers (Kohler et al., 2004). Cultural practices that maintain dense turf are the best way to reduce most weeds; however, cultural control methods alone are not always effective. Cultural practices such as increased N fertilization from 0 to 196 kg ha^{-1} reduced ground ivy only 24% (Kohler et al., 2004), whereas a similar increase in N fertilization provided 86%–96% white clover (*Trifolium repens* L.) control (Voigt et al., 2001). Taller lawn mowing heights are useful in reducing common lawn weeds such as white clover and dandelion (*Taraxacum officinale* F.H. Wigg.) (DeBels et al., 2012; Voigt et al., 2001). The effects of mowing height on ground ivy cover have not been studied, but higher mowing heights likely would not reduce ground ivy to acceptable

ABBREVIATIONS: FeHEDTA, [*N*-[2-[bis(carboxymethyl)amino]ethyl]-*N*-(2-hydroxyethyl)glycinato(3-)]iron); WAA, weeks after application.

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levels (Aaron Patton, personal observation). Ground ivy is found in irrigated and nonirrigated lawns, and both shaded and full sun sites (Patton et al., 2023). As such, few cultural practices can be modified to reduce this weed in lawns; therefore, herbicides are commonly used for control.

Herbicides that effectively control ground ivy include triclopyr (Beck et al., 2014; Kohler et al., 2004; Reicher & Weisenberger, 2007), fluroxypyr (Reicher & Weisenberger, 2007), 2,4-D (Kohler et al., 2004), 2,4-D mixed with other phenoxy herbicides (Borger et al., 2002; Vrabel, 1987), mixtures of 2,4-D and triclopyr (Olson & Wright, 1988; Vrabel, 1987), and aminocyclopyrachlor and metsulfuron (Beck et al., 2014; Brosnan et al., 2012). Patton et al. (2017) reported that herbicides containing 2,4-D, fluroxypyr, triclopyr, iodosulfuron, thiencarbazone, and aminocyclopyrachlor or mixtures of these active ingredients provided the greatest control of ground ivy (>53%). Although ground ivy control from aminocyclopyrachlor is excellent, this herbicide is no longer registered for use in turfgrass systems due to damage to nontarget plants (Patton et al., 2013).

There is a growing demand for alternative weed control strategies that use organic or natural products rather than traditional herbicides (Elmore et al., 2023). In some cases, government regulations restrict or ban the use of pesticides (Elmore et al., 2023). As a result, micronutrient-containing products are now being used as an alternative weed control method in the turfgrass industry (Charbonneau, 2010; Chinery et al., 2012; Hatterman-Valenti et al., 1996; Patton et al., 2019). Previous research reported that applications of borax (sodium borate decahydrate) were effective in controlling ground ivy but not without causing some turfgrass injury (Hatterman-Valenti et al., 1996). Fiesta (FeHEDTA) has been used as selective postemergence weed control with minimum or no injury to turfgrass (Carey et al., 2011; Charbonneau, 2010; Chinery et al., 2012; Hockemeyer & Koch, 2019; Smith-Fiola & Gill, 2014). Although several studies have been conducted to assess the effectiveness of alternative bioherbicides, there is no data comparing the effectiveness of boron and iron-based products and their injury to turfgrass. Further, the only boron-containing product tested previously was borax and it is unclear if other products with boron may be less injurious to the turfgrass while still providing effective weed control. Therefore, the objective of this study was to determine the efficacy of three different boron-containing products and Fiesta for the control of ground ivy and their safety on Kentucky bluegrass.

Core Ideas

- Single applications of boron and an iron-based products provided ground ivy control.
- Boron-based herbicides, regardless of formulation, caused injury to Kentucky bluegrass.
- Chelated iron-based (FeHEDTA) herbicides did not injure Kentucky bluegrass.

2 | MATERIALS AND METHODS

A field experiment was conducted at the W.H. Daniel Turfgrass Research and Diagnostic Center in West Lafayette, IN in 2013–2014. This experiment was conducted in two separate fields. The efficacy of different micronutrient-based products on ground ivy control was tested in a Kentucky bluegrass field with a uniform coverage (>55%) of ground ivy. The phytotoxic injury to Kentucky bluegrass was tested in separate field containing 100% Kentucky bluegrass. Both sites were located within 50 m of one another and were maintained at a 5.0 cm mowing height. The ground ivy-containing site was not fertilized and did not receive supplemental irrigation. The 100% Kentucky bluegrass site was irrigated to prevent wilt, fertilized with 98 kg N ha^{-1} annually, and treated with pre- and postemergence herbicides in the spring of 2013 to prevent and remove annual and perennial weeds, respectively. The soil for both sites was a Mahalasville silty clay loam (fine-silty, mixed, mesic Typic Arigiaquoll) with a pH of 6.9, an organic matter content of 4.9%, and 0.7 ppm B.

In total, four products at two different rates were applied (Table 1). The low and high rates were determined based on rates used by Hatterman-Valenti et al. (1996) or the Fiesta label. Treatments were arranged in randomized complete block design with three blocks and an individual plot size of 1.5 by 1.5 m. A non-treated control plot was included in each block for comparison. Treatments were applied using a CO_2 pressurized backpack sprayers equipped with XR80015 nozzle tips (TeeJet, Spraying Systems Co.) calibrated to deliver 815 L ha^{-1}.

Parameters evaluated include ground ivy coverage, ground ivy injury, turfgrass injury, and turf quality. Coverage was visually rated on a scale of 0%–100% (0% = no visible ground ivy coverage, and 100% = complete ground ivy coverage within each plot). Turfgrass and ground ivy injuries were rated on a scale of 1–9 (1 = completely dead, 7 = acceptable turf injury, and 9 = no injury). Similarly, turf quality was also rated on a scale of 1–9 (1 = completely dead, 6 = acceptable turf quality, and 9 = ideal turf quality). Treatments were applied on 16 October 2013 and rated every week up to 4 weeks after application (WAA). The plots were also rated the following spring on 23 April 2014, 29 May 2014, and 7 July 2014. All data were analyzed using GLIMMIX procedure in SAS (Version 9.4, SAS Institute Inc.). Treatment by date effect was significant so data are presented separately

TABLE 1 Treatments applied to control ground ivy in Kentucky bluegrass at the W.H. Daniel Turfgrass Research and Diagnostic Center (West Lafayette, IN).

Treatment	Active ingredient	Chemical compound	Rate	Approximate cost ($)/ha[a]
Non-treated	–	–	–	–
Borax low	Boron 11.34%	Sodium borate decahydrate ($B_4Na_2O_7 \cdot 10H_2O$), CAS 1303-96-4	15.26 kg ha^{-1}	51.76
Borax high			61.03 kg ha^{-1}	207.04
Boric acid low	Boron 17.47%	Trideuterio borate (BH_3O_3), CAS 14149-58-7	9.76 kg ha^{-1}	50.55
Boric acid high			39.36 kg ha^{-1}	203.78
Solubor low	Boron 20.5%	Disodium octaborate tetrahydrate ($Na_2B_8O_{13} \cdot 4H_2O$), CAS 12280-03-4	8.24 kg ha^{-1}	33.03
Solubor high			32.96 kg ha^{-1}	132.13
Fiesta low	FeHEDTA 26.52%	FeHEDTA [*N*-[2-[bis(carboxymethyl)amino]ethyl]-*N*-(2-hydroxyethyl)glycinato(3-)]iron), CAS 17084-02-5	40.11 L ha^{-1}	529.38
Fiesta high			160.76 L ha^{-1}	2121.70

[a]Based on application rate and bulk pricing found at one or more of the following websites: amazon.com, domyown.com, farmerboyag.com, growitnaturally.com, or lowes.com.

for each date. Means were separated using Tukey test when *F*-tests were significant at $\alpha = 0.05$.

3 | RESULTS

3.1 | Ground ivy injury

The injury symptoms to ground ivy were visible 1 WAA to 3 WAA (Table 2). The high rate of all treatments, the low rate of boric acid, and low rate of Fiesta caused severe injury to ground ivy compared to the non-treated. The only treatments that did not cause significant injury to ground ivy were the low rate of borax 1 WAA and the low rate of borax and Solubor 2 WAA and 3 WAA.

3.2 | Ground ivy cover

The high rate of all boron-containing products and both rates of Fiesta reduced ground ivy cover most on all rating dates compared to the non-treated control plots (Table 3). Generally, there were few differences among borax, boric acid, and Solubor. Control from the high rate of the products tested was evident as early as 1 WAA with all four products reducing ground ivy cover to <34% compared to 78% cover in the non-treated plots. By 2 WAA, the high rate of all boron-containing products and both rates of Fiesta reduced ground ivy cover to <15% compared to 77% in non-treated plots. By 4 WAA, ground ivy cover was <3% in all plots receiving the high rate of boron-containing products. Generally, the low rate of boron-containing products reduced ground ivy cover by 45%–77% compared to the non-treated plots 4 WAA, whereas the low rate of Fiesta provided 80% ground ivy control (16.3% and 81.7% cover, Fiesta Low vs. non-treated, respectively).

These herbicidal effects were observed the following spring (May) and summer (July). The high rates of boron-containing products had ≤9.0% ground ivy cover in July the following year (9 months after application) compared to 66.7% in the non-treated control plots. This is the equivalent of 87% or more control. Fiesta applied at the low and high rate provided 65% or 78% control, respectively, by the end of the study.

3.3 | Boron injury to Kentucky bluegrass

The applications of boron to the plots at the high rate resulted in unacceptable turfgrass injury (<7) to Kentucky bluegrass when rated 2 WAA (Table 4). By 3 WAA, injury was still present and at higher levels than the non-treated plots, though acceptable. By 4 WAA, injury in all plots was similar to the non-treated plot, except the high rate of Solubor. Fiesta was the only treatment that did not injure Kentucky bluegrass,

TABLE 2 Ground ivy injury as influenced by boron and iron-based herbicides applied on 16 October 2013 at W.H. Daniel Turfgrass Research and Diagnostic Center (West Lafayette, IN).

	Ground ivy injury[a]		
Treatment	**1 WAA**	**2 WAA**	**3 WAA**
Non-treated	9.0 a	9.0 a	8.3 a
Borax low	7.7 ab	6.3 ab	5.7 ab
Borax high	3.7 c	2.7 c	1.3 d
Boric acid low	3.7 c	3.3 bc	3.7 bcd
Boric acid high	2.3 c	1.0 c	1.7 cd
Solubor low	7.0 b	6.3 ab	7.3 a
Solubor high	2.0 c	1.3 c	1.0 d
Fiesta low	3.7 c	2.7 c	4.3 bc
Fiesta high	2.3 c	1.7 c	2.7 cd
p-Value	<0.0001	<0.0001	<0.0001

Note: Means within a column sharing common letters are not significantly different at the 0.05 probability level.
Abbreviation: WAA, weeks after application.
[a]Ground ivy injury was rated on a scale of a scale of 1–9 (1 = completely dead and 9 = no injury).

TABLE 3 Ground ivy coverage influenced by boron and iron-based herbicides applied on 16 October 2013 at W.H. Daniel Turfgrass Research and Diagnostic Center (West Lafayette, IN).

	Ground ivy coverage (%)[a]							
Treatment	**0 WAA**	**1 WAA**	**2 WAA**	**3 WAA**	**4 WAA**	**April**	**May**	**July**
Non-treated	78.3	78.3 a	76.7 a	78.3 a	81.7 a	31.7	53.3 a	66.7 a
Borax low	60.0	48.3 abc	40.0 abc	36.7 ab	38.3 abc	19.3	22.3 ab	30.7 ab
Borax high	55.0	25.0 bc	9.0 cd	0.7 b	0.7 c	1.7	2.3 b	4.7 b
Boric acid low	55.0	31.7 bc	20.0 bcd	16.7 b	18.3 bc	12.0	12.7 ab	17.3 ab
Boric acid high	60.0	20.0 c	0.7 d	1.0 b	2.3 bc	8.3	7.0 b	9.0 b
Solubor low	75.0	65.0 ab	48.3 ab	43.3 ab	45.0 ab	11.0	15.3 ab	35.0 ab
Solubor high	73.3	33.3 bc	3.7 cd	0.7 b	1.7 bc	3.7	5.3 b	8.0 b
Fiesta low	70.0	45.0 abc	14.3 bcd	14.0 b	16.3 bc	16.0	16.7 ab	23.3 ab
Fiesta high	71.7	20.0 c	5.7 cd	9.3 b	10.7 bc	3.0	6.3 b	15.0 b
p-Value	0.2382	0.0009	<0.0001	<0.0001	0.0001	0.3260	0.0146	0.0137

Note: Means within a column sharing common letters are not significantly different at the 0.05 probability level. Plots were rated the following spring on 23 April 2014, 29 May 2014, and 7 July, 2014.
Abbreviation: WAA, weeks after application.
[a]Ground coverage was rate on a scale of 0%–100% (0% = no visible ground ivy coverage, and 100% = complete ground ivy coverage within each plot).

even at the higher rate. No injury symptoms were observed the following spring on 29 May 2014.

3.4 | Boron effects on Kentucky bluegrass quality

Kentucky bluegrass quality was influenced by the treatments. Similar to injury, changes in turf quality were visible as early as 2 WAA and were visible up to 4 WAA (Table 4). Although the low and high rates of boron-containing products were not different from one another, the high application rate of borax, boric acid, and Solubor reduced turf quality below acceptable levels (<6). Turf quality was acceptable in most instances when boron-containing products were applied at the low rate. In contrast both high and low rates of Fiesta resulted in the highest turfgrass quality (Table 4).

4 | DISCUSSION

Treatments had a larger impact on ground ivy cover and injury than on turfgrass injury and turf quality indicating the selectivity of the products tested. Ground ivy injury was rapid

TABLE 4 Turfgrass injury and turfgrass quality as influenced by boron and iron-based herbicides at W.H. Daniel Turfgrass Research and Diagnostic Center (West Lafayette, IN).

	Kentucky bluegrass injury[a]			Kentucky bluegrass quality[b]		
Treatment	**2 WAA**	**3 WAA**	**4 WAA**	**2 WAA**	**3 WAA**	**4 WAA**
Non-treated control	9.0 a	9.0 a	9.0 a	6.3 ab	5.7 bc	5.7 ab
Borax low	8.7 a	8.7 ab	8.7 ab	6.3 ab	6.0 bc	5.7 ab
Borax high	6.0 bc	7.7 bc	7.7 ab	5.0 b	5.0 c	5.0 b
Boric acid low	8.0 ab	9.0 a	9.0 a	6.7 ab	6.3 abc	6.3 ab
Boric acid high	6.0 bc	7.3 c	7.3 ab	5.0 b	5.3 bc	5.3 b
Solubor low	8.0 ab	8.7 ab	8.7 ab	6.7 ab	7.0 ab	6.7 ab
Solubor high	5.7 c	7.3 c	7.3 b	5.3 b	5.3 bc	5.3 b
Fiesta low	9.0 a	9.0 a	9.0 a	8.0 a	8.0 a	7.7 a
Fiesta high	9.0 a	9.0 a	9.0 a	8.0 a	8.0 a	7.7 a
p-Value	<0.0001	0.0001	0.0001	<0.0001	<0.0001	0.0038

Note: Means within a column sharing common letters are not significantly different at the 0.05 probability level. Plots were treated with herbicide on 16 October 2013.
Abbreviation: WAA, weeks after application.
[a]Turf injury was rated on a scale of a scale of 1–9 (1 = completely dead, 7 = acceptable turf injury, and 9 = no injury).
[b]Turf quality was rated on a on a scale of 1–9 (1 = completely dead, 6 = acceptable turf quality, and 9 = ideal turf quality).

from both boron-containing treatments and Fiesta. Charbonneau (2010) observed the leaves of dandelion and black medic (*Medicago lupulina* L.) turned black within 24 h and brown and shriveled within 48 h of applying Fiesta. Hockemeyer and Koch (2019) also observed that leaves of affected broadleaf weeds turned dark brown in color and often shriveled and died within 24–48 h following the application of Fiesta. Previous work by Patton et al. (2019) reported that single application of FeHEDTA provided only 33% ground ivy control 2 WAA, but they tested a different ready-to-use product (Ortho Ecosense Lawn Weed Killer containing 1.5% FeHEDTA). A study by Chinery et al. (2012) found two applications of Fiesta were required to control ground ivy when treating with Fiesta in June compared to the 65%–78% control achieved in this experiment from a single application in October. The timing and selection of herbicide applications are also important for effective ground ivy control (Patton et al., 2017). In fall perennial broadleaf weeds are actively growing and storing energy into the roots for winter. Herbicides applied in the fall are more likely to translocate to control the weeds rather than just injuring them (Wilson et al., 2006).

Hatterman-Valenti et al. (1996) observed more than 85% ground ivy control with borax. Hatterman-Valenti et al. (1996) reported that ground ivy control from borax may be weather dependent as boron availability is increased as soil moisture increases (Gupta et al., 1976) and plants can tolerate more boron in cooler weather than in hot and humid conditions (Eaton, 1935). Hatterman-Valenti et al. (1996) reported that borax causes Kentucky bluegrass leaf necrosis up to 6 WAA, which is longer than noted in our study. Glenn et al. (2015) reported <10% injury to St. Augustinegrass [*Stenotaphrum secundatum* (Walter) Kuntze] when applying borax to control southern crabgrass [*Digitaria ciliaris* (Retz.) Koeler]. Alumai et al. (2009) observed temporary browning of a Kentucky bluegrass/perennial ryegrass (*Lolium perenne* L.) species mixture after a borax application. The toxic effect of boron is known to differ depending on the grass species. Grass sensitivity to boron toxicity is reported as: creeping bentgrass (*Agrostis stolonifera* L.) > perennial ryegrass > tall fescue (*Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons.) > Kentucky bluegrass > zoysiagrass (*Zoysia* spp. Willd.) > bermudagrass [*Cynodon* Rich.] (Carrow et al., 2002). Carrow et al. (2002) reported plant tissue boron levels of <5–10 ppm as deficient, 10–60 ppm as sufficient, and 100–1000 ppm as toxic with root uptake differences between species.

Boron toxicity also depends on the soil boron concentration. For example, boron toxicity is most common in arid region soils where limited rainfall often results in high boron concentrations in the soil. Additionally, it is common in the arid Southwest to use recycled irrigation water which is typically high in boron, further contributing to high concentrations in the soil (Carrow et al., 2002). The injury observed on the Kentucky bluegrass from boron applications (6.9 kg boron/ha) was short-lived and may be tolerable by some consumers in order to achieve >85% ground ivy control. Based on discussion above, more injury might be expected if more sensitive turfgrass species are treated, if multiple applications are made, if little rainfall occurs, if soil boron levels are higher before applying boron, and/or if boron is applied in acidic soils. Since the threshold between deficiency and toxicity levels can be narrow for boron (Princi et al., 2016), applicators should use caution when using boron as an alternative control method.

The higher turf quality observed after Fiesta applications was associated with increased green-up due to the chelated iron ingredient. Iron promotes the biosynthesis of chlorophyll pigment (Carrow et al., 2002), which results in darker green for the turfgrass following application. Charbonneau (2010) observed increased green-up of a Kentucky bluegrass and perennial ryegrass lawn mixture within 24 h of applying Fiesta. Hockemeyer and Koch (2019) and Patton et al. (2019) also reported no injury from Fiesta applications to cool-season turfgrasses. Although Fiesta did control ground ivy and improved turf quality through "greening" of the turfgrass and the removal of the weeds, the high cost of this product may be a barrier to wider adoption. Fiesta is estimated to cost \$530–\$2124 to treat one hectare (\$4.92–\$19.73 to treat 1000 ft^2) (Table 1). Comparatively, boron-containing products cost \$51–\$207 per hectare (<\$1.89 to treat 1000 ft^2) and a synthetic herbicide that can effectively control ground ivy would cost \$33–\$132 to treat one hectare (\$0.31–\$1.23 to treat 1000 ft^2). Cost is as a common barrier to the adoption of integrated weed management practices and consumers may not be willing to pay a premium for effective alternatives that are also safe for the turfgrass (Elmore et al., 2023).

This study focused on investigating alternatives to synthetic herbicides. Most organic or natural alternatives for weed control in agricultural cause unacceptable injury to turfgrasses (Patton et al., 2019), which limits the turf manager's options for controlling weeds without synthetic herbicides. Further, of the products that may provide an alternative, there is often confusion on whether these products are allowable in communities with pesticide restrictions. There are multiple categories of natural or organic products including minimum-risk products exempt from EPA registration, products classified as bioherbicides by the EPA, or products certified by the Organic Materials Review Institute (OMRI) (Patton et al., 2019). Borax and Solubor are certified by OMRI for correcting boron deficiencies in plants or soils but OMRI states that they "Must not be used as an herbicide, defoliant or desiccant" (OMRI, 2023). Similarly, OMRI (2023) certified boric acid for insect control but its use is not allowable for weed control. Fiesta is not an OMRI-registered product (OMRI, 2023) but instead is classified as a bioherbicide by the US EPA (USEPA, 2023) under registration no. 67702-26-87865 (Anonymous, 2020). Although chelated iron products are not certified by OMRI for weed control, they are often considered allowable for use in sites that restrict pesticide use (Kao-Kniffin, 2020).

5 | CONCLUSIONS

The high rate of all boron-based products and the iron-based herbicide used in this study provided good (75%–90%) to excellent (>90%) ground ivy control. Although boron-containing products were effective in controlling ground ivy, they caused unacceptable injury and reduced the quality of the Kentucky bluegrass turf. Further, all boron-containing products equally injured the turfgrass indicating that a "safe" formulation is not currently available. This study did not assess repeated applications of boron, but there is concern that multiple applications of lower rates would lead to an accumulation in the soil and cause turfgrass toxicity. Fiesta did not cause any turfgrass injury and produced the highest quality turf while also providing 65% or 78% control by the end of the study with the low and high rates, respectively. Among the four products tested, Fiesta herbicide offers the best combination of turfgrass safety and weed control, although the high product cost may limit implementation. There is much more that can be learned about the use of micronutrient-based products for the control of turfgrass weeds. Future studies might explore different rates, formulations, or combinations of micronutrients or the integration of practices as well as the safety (i.e., toxicity) on other desirable turfgrass species.

AUTHOR CONTRIBUTIONS

Naba R. Amgain: Formal analysis; writing–original draft. **Leslie L. Beck**: Date curation; investigation; methodology; and writing–review and editing. **Aaron J. Patton**: Conceptualization, funding acquisition; methodology; project administration; supervision; writing–review and editing.

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CONFLICTS OF INTEREST

The authors report no conflicts of interest.

ORCID

Naba R. Amgain https://orcid.org/0000-0003-3809-3049
Aaron J. Patton https://orcid.org/0000-0003-3870-7709

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