THE EFFECTS OF DAZOMET ON ANNUAL BLUEGRASS SEED VIABILITY

By

Thomas O. Green

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Crops and Soil Sciences—Doctor of Philosophy

2020

ABSTRACT

THE EFFECTS OF DAZOMET ON ANNUAL BLUEGRASS SEED VIABILITY

By

Thomas O. Green

A major concern regarding creeping bentgrass (*Agrostis stolonifera*) putting greens is annual bluegrass (*Poa annua)* invasion. With methyl bromide fumigation now being highly restricted, alternatives must be investigated to curtail weed seed soil infestations. Currently, dazomet is the only fumigant labeled for annual bluegrass control in turfgrass systems. Therefore, research questions related to dazomet efficacy come to the forefront such as how soil texture and depth of seed bank affect efficacy as well as which application rate is most effective within a soil. A study was designed to garner data as to the depth of soil removal needed to reduce annual bluegrass seedling emergence in a newly renovated putting green. Research was conducted in different seasons, summer and fall, respectively; to evaluate seedling emergence across five soil removal depths in four sampling sites. Cores were collected from four golf courses in southeastern Michigan, subdivided into different soil removal depths, potted in sterile soil media, and established in a growth chamber. Results suggest that excavating soil to a depth of 2.54 cm, or more prudently, 3.81-cm depth could minimize annual bluegrass competition in a creeping bentgrass putting green, e.g., annual bluegrass emergence was observed to be greatest in the upper soil depths (1.27 to 3.81cm) in both seasons with minimal emergence (<1.1 plants/0.0186 m^2) below the 5.08-cm soil removal depth treatment. In order to determine the effectiveness of dazomet deep within a soil, eighty glass jars (0.945 L) were filled with soil, a loamy

sand and sandy clay loam, and 220 seeds of annual bluegrass (placed in a nylon mesh bag to ease retrieval) were buried at depths of 3.0 cm and 6.0 cm. Dazomet treatments consisted of the following: 294, 439, 588 kg•ha^{-1}, a negative control (no fumigation), and a positive control (autoclaved seed and soil at ~121 °C). Irrigation was applied at an equivalent rate of 2.54 cm•d^{-1} of water to activate and incorporate the fumigant within the soil profile. All treated jars were then sealed with metal lids and subjected to a 21-d fumigation exposure period at ~25° C in darkness. Afterward, the nylon-bagged seeds were recovered, and 2,400 seeds were warm germination tested in paper-blotter-lined petri dishes to determine the effects of dazomet on seed mortality. Data results indicate that regardless of the rate of fumigation, seedling emergence was suppressed in both soil types and seed placement depths. The simulated high-barrier tarping and standard water sealing methods increased dazomet efficacy against seed germination and seedling emergence. Therefore, it may be reasonable to assume that dazomet is a highly viable fumigant to control annual bluegrass seed infestations in turfgrass systems.

To turfgrass researchers. Be steadfast in your pursuit to contribute to the collection of scientific knowledge.

ACKNOWLEDGEMENTS

Thank you to all my family and everyone including my professors John Rogers, III, James Crum, Jim Flore, and Eunice Foster, and a special acknowledgement to the following for their financial support of this research: the Michigan Turfgrass Foundation and Carl Schwartzkopf, Pastor Chris McCoy and his wife, Denise McCoy at New Level Sports Ministries alongside the Battle Creek (MI) Community Foundation. Also, thank you to a superb group of golf course superintendents plying their trade in and around metropolitan Detroit and the southeast region of Michigan: Mike Edgerton (retired), Meadowbrook Country Club (CC); Colin Seaborg, Barton Hills CC; Brian Schweihofer, Franklin Hills CC; and Gary Thommes, Red Run Golf Club. Their field sites were perfect for our research studies on annual bluegrass seed control in turfgrass systems. More so my gratitude to the Jesse Sholl and Adam Palmiter and the Michigan State University Turf Team for maintaining the Hancock Turfgrass Research Center to the highest standard.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

A major concern with creeping bentgrass (*Agrostis stolonifera*) putting greens is the high incidence of annual bluegrass (*Poa annua*) invasion. A genetically diverse and prolific seed producer (Beard et al., 1978; Ellis, 1971; Gibeault and Goetze, 1973; Law, 1981; Timm, 1965; Tutin, 1957; Wells, 1974; Youngner, 1959), annual bluegrass thrives in highly cultured turfs (Barkworth et al., 2003; Huff, 1999; La Mantia and Huff, 2011; Warwick, 1979), and can provide a high-quality putting surface. However, most golf course superintendents consider it an invasive weed for which they go to great lengths controlling it in their greens (Vargas and Turgeon, 2004). Previous research has not only demonstrated the colonization of distinct, aggressive populations in greens (Sweeney and Danneberger, 1995, 1997), but also, the profuse quantities that remain viable in the soil seed bank (Branham et al., 2004; Peachy et al., 2001). Although some studies quantified survival of buried annual bluegrass seed in crop production fields (Peachy et al., 2001), research has not been conducted on the amount of soil removal needed to reduce seed germination in putting greens.

LITERATURE REVIEW

Annual bluegrass control in turfgrass systems

Annual bluegrass is a turfgrass species that is adapted to many climatic conditions. highly competitive with other grasses in stands of intensively cultured turfs. In Michigan, creeping bentgrass putting greens have been invaded frequently and supplanted by annual bluegrass. Although annual bluegrass putting green can offer excellent performance characteristics, many turfgrass managers consider it a weed species, and expend much effort to control annual bluegrass in golf course turf (Vargas and Turgeon, 2004). One of the reasons being that it is highly susceptible to diseases, and insect pests which can decimate annual bluegrass turfs if not controlled (Vargas and Turgeon, 2004). More so the seed bank can be problematic. Sand topdressing of putting greens has increased rootzones depths over time (McCarty et al., 2005; Skolruski et al., 2010; Whitlark and Hummel, 2018), and buried annual bluegrass seed deep within the rootzone profile and is the reason why golf course renovations have peaked in recent years (Jones, 2019).

Five principles usually dictate a renovation: major turf loss due to abiotic and biotic stress, loss of putting green due to collar encroachment, excessive organic matter accumulation, need for architectural design improvement, and invasion of undesirable turfgrass species affecting surface playability (Foy and Gilhuly, 2015). In the cool-season region, conversion to a desirable grass species such as a creeping bentgrass is one option, but the cost of renovation is a big concern. Partial removal of an existing rootzone, a resurfacing as it is commonly called, is an economically viable option, costing 20% of a total rebuild (White, 2006). More so complete rootzone removal may not be the best nor necessary option in most cases. For cool-season grass species, it has been suggested that only the upper 2.54 cm to 7.62 cm of existing rootzone be removed (Whitlark and Hummel, 2018) when replacing a turfgrass variety with an improved variety by reseeding or sodding. This removal amount would not require adding more rootzone material because of the high frequency sand topdressing. These are the efforts guiding golf course to become more environmentally friendly by decreasing pesticide, fertilizer, and water inputs (Gilhuly, 2016; Jones, 2017). Therefore, a cost-effective renovation method must be identified to reduce annual bluegrass seedling emergence in a putting green. Perhaps excavating to at least a 2.54-cm depth, or more prudently to a 3.81- to 5.08-cm depth of an existing rootzone would have sufficient efficacy to minimize weed invasion when renovating with or without soil fumigants.

Soil fumigation methods

What once was the fumigant of choice for golf course renovation projects, methyl bromide has been phased out of agricultural systems by the U.S. Environmental Protection Agency (EPA) because it is an ozone-depleting substance (ODS). The phaseout has created a quandary as to the availability of effective yet economically viable alternative soil sterilization methods. Presently, there are only six-EPA registered fumigants available for use; dazomet and metam sodium/potassium, for instance, have been observed to provide adequate control of various soil pests and a viable option for the turfgrass industry (Branham et al., 2004; Park and Landschoot, 2003). When applied to the site and incorporated into the soil, both fumigants react with water to produce a gaseous methyl isothiocyanate (MITC) formulation for which great care must be taken to prevent atmospheric losses from the edaphic environment. Thus, application sites are often tarped with polyethylene sheets of varying thickness and permeability thresholds to reduce MITC losses. However, some research on dazomet efficacy has discovered that acceptable control of grassy weeds could be achieved with reduced application rates in uncovered treatment plots (Bravo et al., 2018; Jeffries et al., 2017; Park and Landschoot, 2003).

SUMMARY

It is critical to determine annual bluegrass seed germination characteristics within soils regarding renovation practices involving fumigation with dazomet. Research indicates that dazomet is effective against soil-borne pest infestations, with or without, post-fumigation tarp coverage of site.

REFERENCES

REFERENCES

Barkworth, M.E., K.M. Capels, S. Long, and M.B. Piep, editors. 2003. Flora of North America, *Magnoliophyta: Commelinidae* (in part) *Poaceae*. 25(2). Oxford Univ. Press. New York.

Bravo, J.S., T.O. Green, J.R. Crum, J.N. Rogers, S. Kravchenko, and C.A. Silcox. 2018. Evaluating the efficacy of dazomet for the control of annual bluegrass seed germination in renovated turf surfaces. HortTechnology. 28:1-4.

Branham, B.E., G.A. Hardebeck, J.W. Meyer, and Z.J. Reicher. 2004. Turfgrass renovation using dazomet to control the *Poa annua* L. soil seed bank. HortScience. 39:1763-1767.

Beard, J.B., P.E. Rieke, A.J. Turgeon, and J.M. Vargas, Jr. 1978. Annual bluegrass (*Poa annua* L.): description, adaption, culture, and control. Agricultural Experiment Station Research Report. Michigan State University. East Lansing, MI.

Ellis, W.M., B.T.O. Lee, and D.M. Calder. 1971. A biometric analysis of populations of *Poa annua* L. Evolution. 25: 29-37.

Gibeault, V.A. and N.R. Goetze. 1973. Annual meadowgrass. J. Sports Turf Res. Inst. 48: 9-19.

Huff, D.R. 1999. For richer, for *Poa*: cultivar development of greens-type *Poa annua*. USGA Green Section Record. 37(1): 11-14.

Jeffries, M.D., T.W. Gannon, W.C. Reynolds, F.H. Yelverton, and C.A. Silcox. 2017. Herbicide applications and incorporation methods affect dazomet efficacy on bermudagrass. HortTechnology. 27:24-29.

Law, R. 1981. The dynamics of colonizing population of *Poa annua*. Ecology. 62: 1267-1277.

McCarty, L.B., M.F. Gregg, J.E. Toler, J.J. Camberato, and H.S. Hill. 2005. Minimizing thatch and mat in a newly seeded creeping bentgrass golf green. Crop Sci. 45: 1529-1535.

Park, B.S. and P.J. Landschoot. 2003. Effects of dazomet on annual bluegrass emergence and creeping bentgrass establishment in turf maintained as a golf course fairway. Crop Sci. 43:1387-1394.

Peachey, R.E., J.N. Pinkerton, K.L. Ivors, M.L. Miller, and L.W. Moore. 2001. Effects of soil solarization, cover crops, and metam on field emergence and survival of buried annual bluegrass (*Poa annua*) seed. Weed technology. 15(1): 81-88.

Skorulski, J., J. Henderson, and N. Miller. 2010. Topdressing fairways: more is better. USGA green section record. March/April. 48(2): 15-17.

Sweeney, P.K. and T.K. Danneberger. 1995. RAPD characterization of *Poa annua* L. populations in golf course greens and fairways. Crop Science. 35: 1676-1680.

Sweeney, P.K. and T.K. Danneberger. 1997. Annual bluegrass segregation on greens and fairways. Golf Course Management. 65(4): 49-52.

Timm, G. 1965. Biology and systematics of *Poa annua*. Feitschriftfuer Acher-und Pflanzenbau. 122: 267-294.

Tutin, T.G. 1957. A contribution to the experimental taxonomy of *Poa annua* L. Watsonia. 4: 1-10.

Vargas, J.M., Jr. and A.J. Turgeon. 2004. *Poa annua*: physiology, culture, and control of annual bluegrass. John Wiley and Sons, Inc. Hoboken, NJ.

Warwick, S.I. 1979. The biology of Canadian weeds: 37. *Poa annua* L. Canadian Journal of Plant Science. 59(4): 1053-1066.

Wells, G.J. 1974. The biology of *Poa annua* and its significance in grassland. Herbage Abstracts. 44: 385-391.

Youngner, V.G. 1959. Ecological studies on Poa annua in turfgrasses. Journal of the British Grassland Society. 14(4): 233-247.

CHAPTER 1: ANNUAL BLUEGRASS: GERMINATION OF VIABLE SEED IN VARIOUS PUTTING GREEN SITES AND SOIL REMOVAL DEPTHS

ABSTRACT

A major concern with many creeping bentgrass (*Agrostis stolonifera*) putting greens is annual bluegrass (*Poa annua*) invasion. The study was designed to assess or investigate the depth of soil removal needed to reduce annual bluegrass seedling emergence in a newly renovated putting green. Research was conducted in summer and fall to evaluate seedling emergence across five soil removal depths at four sampling sites. Cores were collected from four golf courses in southeastern Michigan, subdivided into different soil removal depths, potted in sterile soil media and established in a growth chamber. Results suggest that excavating soil to a depth of 2.54 cm, or more practically, 3.81-cm depth could curtail annual bluegrass infestations in a creeping bentgrass putting green because emergence was greatest in the upper soil depths (1.27 to 3.81 cm) in both seasons with nominal emergence (<1.1 plants/0.0186 m^2) below the 5.08-cm soil removal depth treatment.

INTRODUCTION

Recently, golf course renovations have peaked because of aging and functionally deficient components such as putting greens (Jones, 2019), and five principles usually dictate a renovation: major turf loss due to abiotic and biotic stress, loss of putting green due to collar encroachment, excessive organic matter accumulation, need for architectural design improvement, and invasion of undesirable turfgrass species affecting surface playability (Foy and Gilhuly, 2015). In the cool-season region, conversion to a desirable grass species such as a creeping bentgrass is one option, but the cost of renovation is a big factor. Partial removal of an existing rootzone, a resurfacing as it is commonly called, is an economically viable option, costing 20% of a total rebuild (White, 2006). More so a complete rebuild with total rootzone removal may not be the best nor necessary option in most cases. For cool-season grass species, it has been suggested that only the upper 2.54 to 7.62 cm of existing rootzone be removed (Whitlark and Hummel, 2018) when replacing a turfgrass variety for an improved variety by reseeding or sodding. This removal amount (2.54 to 7.62 cm) would not require adding more rootzone material because most putting greens greater than 10 years old have sufficient additions of sand topdressing making it deeper than the original construction depth (McCarty et al., 2005; Skolruski et al., 2010; Whitlark and Hummel, 2018). Additionally, these frequent sand additions have buried annual bluegrass seed deep within the rootzone profile.

Superintendents are searching for ways to improve putting surfaces not only to appease the customers, but also, to decrease pesticide, fertilizer, and water inputs in order to be more environmentally friendly (Gilhuly, 2016; Jones, 2017). Consequently, a cost-effective renovation method must be identified to reduce annual bluegrass seedling emergence in a putting green. Perhaps excavating to at least a 2.54-cm depth, or more prudently to a 1.27- to 5.08-cm depth of an existing rootzone would have sufficient efficacy to minimize weed invasion when renovating with or without soil fumigants. The objective of this study is to evaluate the effects of putting green site, soil removal depth, and season on annual bluegrass seedling emergence.

MATERIALS AND METHODS

Observations on annual bluegrass seedling emergence were conducted in summer and fall seasons, i.e., 20 Aug. 2015 and 16 Oct. 2015 at the Michigan State University (MSU), Plant, Soil, and Microbial Sciences Growth Chamber Facilities, East Lansing, MI. Sampling sites were four golf courses with native soil, “push-up” greens (Hurdzan, 2004) located in southeastern Michigan (Table 1): Barton Hills Country Club (CC), Ann Arbor, MI; Franklin Hills CC, Franklin, MI; Meadowbrook CC, Northville, MI; and Red Run Golf Club (GC), Royal Oak, MI. The treatment was soil removal depth of the putting green rootzone (1.27, 2.54, 3.81, 5.08, and 7.62 cm). During each season, 15 soil cores were randomly removed from a single putting green at each sampling site to assess annual bluegrass seed germination at different soil removal depths. A 10.16-inch-diameter golf cup cutter (Lever Action Hole Cutter, Par Aide, Lino Lakes, MN) was used to remove cores to a depth of 7.62 cm from the sample greens. As shown in Table 2, distinct differences among study sites may reflect both the variation in topdressing application rates as most were extensively topdressed over the past 25 years (M. Edgerton, B. Schweihofer, C. Seaborg, G. Thommes, personal communication). Barton Hills CC had a relatively shallow sand topdressing layer based on the rationale that its silt and clay percentage sharply increased to 25.4% (indicative of a sandy-loam native layer) at the 5.08-cm soil removal depth while all others were between 4% and 5%.

A total of 60 cores were collected at each season. The cores were brought to the greenhouse and subjected to soil removal depth treatments. Cores from each season and each sampling site were randomly assigned to these treatments with three cores per soil removal depth for each site and season.

Table 1. A description of the golf course putting greens; the approximate age, species composition, and cultural regime used as of 2015.

Site	Annual bluegrass to creeping bentgrass ratio (percentage)	Putting green age (years)	Sand topdressing frequency (no./month)	Annual nitrogen applied ($lb/1000\ ft^2$) [z]
Barton Hills Country Club (Ann Arbor, MI)	70:30	98	2 or 3	2.5
Franklin Hills Country Club (Franklin, MI)	60:40	90	2	2.7
Meadowbrook Country Club (Northville, MI)	95:5	95	2 or 3	4.2
Red Run Golf Club (Royal Oak, MI)	80:20	100	2	5.0

[z] $1\ lb/1000\ ft^2 = 48.8243\ kg \cdot ha^{-1}$
Information provided by personal communication with golf course superintendents M. Edgerton, B. Schweihofer, C. Seaborg, and G. Thommes

Table 2. Percentage of silt and clay in the soil removal depth cores in 2015.

Soil removal depth (cm) [y]	BH [z]	FH	MB	RR
	Silt and clay (%) [x]			
1.27	7.1	5.3	4.9	7.0
2.54	4.3	4.8	4.8	8.0
3.81	5.5	4.7	4.7	5.8
5.08	25.4	4.6	5.1	3.7
7.62	30.5	4.6	7.7	2.7

[z] The study sites were golf courses located in southeastern Michigan and the following: Barton Hills Country Club (CC) (BH), Franklin Hills CC (FH), Meadow Brook CC (MB), and Red Run Golf Club (RR).
[y] Soil removal depth treatments accomplished by a core-slicing apparatus (Soil and Plant Nutrient Laboratory, Michigan State University, East Lansing); 1 inch = 2.54 cm.
[x] Silt and clay particle sizes were measured by hydrometer method (Soil and Plant Nutrient Laboratory Michigan State University, East Lansing).

Soil of each core was removed to the respective depth treatment with a core-slicing apparatus (MSU Soil and Plant Nutrient Laboratory, East Lansing, MI) which could be described as an open-topped wooden box (11.4 cm wide x 30.4 cm long) with side slots so that a sawblade could precisely separate soil cores into depth intervals of 0.0 to 1.27, 1.27 to 2.54, 2.54 to 3.81, 3.81 to 5.08, and 5.08 to 7.62 cm (Figure 1). Although some sections unintentionally broke apart, the soil depth treatments were placed level with the surface of the potting media (55% sphagnum peat moss with equal parts processed pine bark, perlite, and vermiculite). All treatment pots (16.5 cm diameter x 11.4 cm depth) were then placed into a controlled-environment growth chamber described by Merewitz et al. (2011) with conditions set to maintain a 500 µmol m^{-2} s^{-1} photosynthetic photon flux density, day and night temperatures of 25 °C and 20 °C, respectively, and regulated at 67% relative humidity with a 14-h photoperiod. Fertilization consisted of weekly applications of 50% Hoagland solution (Hoagland and Arnon, 1950) through mist-nozzle irrigation with ~0.2 cm of water applied in a single irrigation period. For this experiment, emerged annual bluegrass seedlings were counted 35 d after placing soil removal depth treatments in experimental pots (DAP). This time duration was chosen to give sufficient time for seed germination and seedling emergence to occur in all experimental treatments.

Data analysis was conducted using PROC GLIMMIX in SAS (version 9.4, SAS Institute, Cary, NC). Two types of statistical analyses for emergence data were performed. In the first analysis the individual golf courses were treated as a fixed factor and the effects of soil removal depth and season were examined in each course. Statistical model for the analysis consisted of the fixed effects of soil removal depth, golf course site, and season along with their interactions.

Figure 1. Photos show soil removal depth treatments accomplished by a core-slicing apparatus provided by the Michigan State University Soil and Plant Nutrient Laboratory in 2015 at East Lansing, MI; 1 inch = 2.54 cm.

Normality and equal variance assumptions have been checked using normal probability plots and side-by-side box plots, respectively. Since there were substantial differences among data variances of site and season, heterogeneous variance model was fitted with separate variance estimates for each site within each season. When the interaction effects were found to be statistically significant, the interactions were examined using slicing (simple effect tests), and mean separations among the cell means. When the interactions appeared to be spurious or representing differences in magnitude of the studied effects, marginal means were reported and compared. The second analysis treated individual golf course sites as a random factor and compared the performance of soil removal depth treatments across all individual golf courses, representing the entire population of similar golf courses in the state of Michigan. Statistical tests were conducted at 0.05 level of probability. Mean separations were performed based on Fisher's least significant difference (LSD) (Ott and Longnecker, 2001).

RESULTS AND DISCUSSION

Results of main effect and interaction tests for seedling emergence (number of plants/0.0186 m^2) at 35 DAP are presented in Table 3. Since the interactions among soil removal depth, sites (golf course), and seasons were statistically significant, we first examined performance of all depth treatments within individual sites of each season (Table 4). The data suggests that in all sites and seasons there is at least a numeric trend present of lower annual bluegrass emergence at greater depths with statistically significant differences between 1.27- and 7.62-cm depth in a couple of sites.

Table 3. Analysis of variance results for annual bluegrass emergence following soil removal depth treatments 35 d after placing treatment in potting media in 2015 at East Lansing, MI.

Source of variation	df	*P* > F
Soil removal depth (SR)	4	<0.0001*
Site (S) [z]	3	<0.0001*
SR*S	12	0.0031*
Season (SE) [y]	1	0.0006*
SE x SR	4	0.0038*
SE x S	3	0.0025*
SE x SR x S	12	0.0525*

[z] The study sites were golf courses located in southeastern Michigan.
[y] The study was initiated on 20 Aug. (summer) and replicated 16 Oct. (fall).
* Mixed factor effects ANOVA model in SAS (version 9.4; SAS Institute, Cary, NC) at $P \leq 0.05$; germination was based on number of plants/0.0186 m^2 where 1 plant/0.0186 m^2 = 53.8196 plants/m^2; 0.2 ft^2 = 0.0186 m^2).

Table 4. Effect of season x soil removal depth x site (golf course) on annual bluegrass emergence 35 d after placing treatment in potting media in 2015 at East Lansing, MI.

Soil removal depth (cm) [x]	Summer [z]				Fall			
	BH [y]	FH	MB	RR	BH	FH	MB	RR
	Mean plants (no./0.0186 m^2) [w]							
1.27	11.0 bcd [v]	4.0 bcde	7.3 bcd	6.0 bcd	94.3 a	3.7 bcde	10.3 bcd	17.7 bc
2.54	24.7 bc	0.3 de	1.7 cde	6.0 bcd	47.3 b	0 e	1.3 cde	2.7 cde
3.81	2.0 cde	0.3 de	1.0 cde	0.7 cde	34.3 bc	0 e	1.3 cde	2.0 cde
5.08	1.3 cde	1.0 cde	0 e	0 e	3.0 bcde	0 e	2.7 cde	0.7 cde
7.62	0 e	0 e	0.3 de	0 e	0.3 cde	0.3 de	0 e	0.3 de

[z] The study was initiated on 20 Aug. (summer) and replicated 16 Oct. (fall).
[y] The study sites were golf courses located in southeastern Michigan and the following: Barton Hills Country Club (CC) (BH), Franklin Hills CC (FH), Meadow Brook CC (MB), and Red Run Golf Club (RR).
[x] Soil removal depth treatments accomplished by a core-slicing apparatus (Soil and Plant Nutrient Laboratory, Michigan State University, East Lansing); 1 inch = 2.54 cm.
[w] 1 plant/0.0186 m^2 = 53.8196 plants/m^2; 0.2 ft^2 = 0.0186 m^2.
[v] Mean values separated in accordance to Fisher's protected least significant difference at $P \leq 0.05$.

For instance, at the 1.27-cm depth in summer season, Barton Hills CC and Red Run GC had mean plant counts of 11 and 6 plants/0.0186 m^2, respectively; but as depth increased to 7.62 cm, both sites had no presence of annual bluegrass seedling emergence. Similarly, in fall season, Barton Hills CC, Red Run GC, and Meadowbrook CC had mean plant counts of 94.3, 17.7, and 10.3 plants/0.0186 m^2, respectively; and 0.3 or less annual bluegrass plants/0.0186 m^2 at the 7.62-cm depth. This effect of soil removal depth x site x season could be described as an interaction of magnitude.

Significant two-way interactions such as soil removal depth x season and soil removal depth x site were observed and could also be described as interactions of magnitude with consistent trends of greater seedling emergence in the upper soil profile at all sites for both seasons. Thus, it is best to examine main effects of soil removal depth and compare marginal effects of depth treatments (Table 5). Time of sampling may affect annual bluegrass emergence. Soil removal depth x season interaction results suggest that seedling emergence in the upper soil profile was greatest in October compared to the same treatment in August. This comparison was conducted while treating golf course site as a random effect, thus expanding the applicability of the findings to a broad range of similar golf courses. However, the high variability in emerged seedlings among the sites could be due to the varying topdressing regimes practiced by each golf course (Table 2). Barton Hills CC had less sand topdressing compared to the other sites, and thus, did not bury annual bluegrass seed within the putting green rootzone, leaving more seed in their respective uppermost soil depths. Seasonal temperature fluctuation may have affected annual bluegrass emergence in August and October. R.N. Calhoun (personal communication) suggested that the highest

Table 5. Effect of season x soil removal depth on annual bluegrass emergence 35 d after placing treatments in potting media in 2015 at East Lansing, MI.

Soil removal depth (cm) [y]	Summer [z]	Fall
	Mean plants (no./0.0186 m^2) [x]	
1.27	7.1 bc [w]	31.5 a
2.54	8.2 bc	12.8 b
3.81	1.0 cd	9.4 bc
5.08	0.6 cd	1.6 bcd
7.62	0.1 d	0.3 cd

[z] The study was initiated on 20 Aug. (summer) and replicated 16 Oct. (fall); sites were golf courses located in southeastern Michigan and the following: Barton Hills Country Club (CC), Franklin Hills CC, Meadow Brook CC, and Red Run Golf Club.

[y] Soil removal depth treatments accomplished by a core-slicing apparatus (Soil and Plant Nutrient Laboratory, Michigan State University, East Lansing); 1 inch = 2.54 cm;

[x] 1 plant/0.0186 m^2 = 53.8196 plants/m^2; 0.2 ft^2 = 0.0186 m^2.

[w] Mean values separated in accordance to Fisher's protected least significant difference at $P \leq 0.05$.

germination rates occurred at soil temperatures between 10 to 22 °C, 74% and 73% respectively, but only 26% and 19% germinated respectively, at 22 °C and above. Calhoun (2010) observed that 100% of seed germination was between 10 to 24 °C, but none germinated when soil temperatures were below 10 °C. Wu et al. (1987) also noticed that seed stored at 12 and 25 °C fluctuated temperatures showed greater percentage of seed germination compared to storage at a constant temperature. Annual bluegrass emergence in creeping bentgrass greens was observed to be highest in spring and autumn rather than summer (Branham, 1991; Kaminski and Dernoeden, 2007; Shem-Tov and Fennimore, 2003). Similarly, Beard et al. (1978), Engel (1967), and Hovin (1957) noted that temperature fluctuation (10 to 21 °C) promoted annual bluegrass germination rate, and that consistency of air temperature, either high or low, halted seed germination. Significant differences were observed among soil removal depth treatments (Table 6). The 1.27-cm soil removal depth had greatest presence of annual bluegrass seed than all other soil removal treatments. Minimal emergence (<1.1 plants/0.0186 m^2) was observed below the 5.08-cm soil removal depth.

CONCLUSIONS

Competition between annual bluegrass and a desirable grass species is a major concern as they vie for valuable resources such as water, nutrients, and light. Therefore, some degree of soil removal may be necessary when considering a putting green renovation. Research data suggest a conservative soil excavation, at least 2.54-cm depth, and more prudently 3.81- to 5.08-cm depth may provide golf course superintendents the

Table 6. Effect of soil removal depth on annual bluegrass emergence 35 d after placing treatments in potting media in 2015 at East Lansing, MI.

Soil removal depth (cm) [z]	Mean plants (no./0.0186 m^2) [y]
1.27	19.3 a [x]
2.54	10.5 b
3.81	5.2 bc
5.08	1.1 c
7.62	0.2 c
LSD	8.4

[z] Soil removal depth treatments accomplished by a core-slicing apparatus (Soil and Plant Nutrient Laboratory, Michigan State University, East Lansing). The study was initiated on 20 Aug. (summer) and replicated 16 Oct. (fall); sites were golf courses located in southeastern Michigan and the following: Barton Hills Country club (CC), Franklin Hills CC, Meadow Brook CC, and Red Run Golf Club; 1 inch = 2.54 cm.

[y] 1 plant/0.0186 m^2 = 53.8196 plants/m^2; 0.2 ft^2 = 0.0186 m^2.

[x] Mean values separated in accordance to Fisher's protected least significant difference at $P \leq 0.05$.

greatest results in regard to minimum annual bluegrass emergence following renovation. Results also suggest the critical need to remove the upper soil layer if superintendents plan seeding operations in autumn more so than summer because temperature seems to be a factor in seedling emergence. Perhaps to get a better understanding on the variability in seedling emergence among sites, a study could be conducted where multiple greens at an individual site be tested for variation. However, it has been determined that annual bluegrass growing in putting greens is a distinct population to that of grass growing elsewhere. So that regardless of golf course sites, the greens were colonized by an annual bluegrass population most adaptive to a putting green environment (Sweeney and Danneberger, 1995, 1997). Current research is delving into a method of scarifying the soil, more aptly known as fraise/fraze mowing (Minnick, 2018), to determine the effectiveness of this procedure to control seedling emergence at various soil depths with and without a fumigant (dazomet). Therefore, practitioners might consider these renovation suggestions to minimize plant competition when establishing a creeping bentgrass putting green.

REFERENCES

REFERENCES

Beard, J.B., P.E. Rieke, A.J. Turgeon, and J.M. Vargas, Jr. 1978. Annual bluegrass (*Poa annua* L.): Description, adaption, culture, and control. Agr. Expt. Sta. Res. Rpt. Michigan State Univ. East Lansing, MI.

Branham, B.E. 1991. Dealing with *Poa annua*: Understanding the strength and weaknesses of annual bluegrass is the first step in developing a successful management program. Golf Course Mgt. 59(9):46-60.

Calhoun, R.N. 2010. Growing degree days as a method to characterize germination, flower pattern, and chemical flower suppression of a mature annual bluegrass [*Poa annua* var *reptans* (Hauskins) Timm] fairway in Michigan. Diss. Michigan State Univ. East Lansing, MI.

Engel, R.E. 1967. Temperatures required for annual bluegrass and colonial bentgrass. Golf Course Superintendent. 35(9):20, 23.

Foy, J. and L. Gilhuly. 2015. Time to rebuild the greens or is it? Many factors must be considered before undertaking a putting green reconstruction project. USGA Greens Sect. Rec. 53(19):1-9.

Gilhuly, L. 2016. A light at the end of the tunnel? U.S. Golf Assn. Far Hills, NJ.

Hoagland, D.R. and D.I. Arnon. 1950. The water-culture method for growing plants without soil. California Agr. Expt. Sta. Bul. 347:29-31.

Hovin, A.W. 1957. Germination of annual bluegrass seed. Southern California Turf Cult. 7(2):13.

Hurdzan, M.J. 2004. Golf greens: History, design, and construction. Wiley, Hoboken, NJ.

Jones, P. 2019. Parting shots: Futurama. Golf Course Ind. 51(1):82.

Jones, S. 2017. Less turf + better turf = better golf: In an effort to make golf better for the budget and better for the golfer, courses take a close look at where the green goes. Golfdom. 73(9):16-18, 22, 24.

Kaminski, J.E. and P.H. Dernoeden. 2007. Seasonal *Poa annua* L. seedling emergence patterns in Maryland. Crop Sci. 47:775-781.

McCarty, L.B., M.F. Gregg, J.E. Toler, J.J. Camberato, and H.S. Hill. 2005. Minimizing thatch and mat in a newly seeded creeping bentgrass golf green. Crop Sci. 45:1529-1535.

Merewitz, E.B., T. Gianfagna, and B. Huang. 2011. Photosynthesis, water use, and root viability under water stress as affected by expression of *SAG12-ipt* controlling cytokinin synthesis in *Agrostis stolonifera*. J. Expt. Bot. 62:383-395.

Minnick, J. 2018. 5 years of fraze mowing evolution. SportsTurf. 34(3):18-21.

Ott, R.M. and M. Longnecker. 2001. An Introduction to Statistical Methods and Data Analysis, 5th ed. Duxbury, Pacific Grove, CA.

Shem-Tov, S. and S.A. Fennimore. 2003. Seasonal changes in annual bluegrass (*Poa annua*) germinability and emergence. Weed Sci. 51:690-695.

Skorulski, J., J. Henderson, and N. Miller. 2010. Topdressing fairways: More is better. USGA Green Sect. Rec.48(2):15-17.

Sweeney, P.K. and T.K. Danneberger. 1995. RAPD characterization of *Poa annua* L. populations in golf course greens and fairways. Crop Sci. 35:1676-1680.

Sweeney, P.K. and T.K. Danneberger. 1997. Annual bluegrass segregation on greens and fairways. Golf Course Mgt. 65(4):49-52.

White, B. 2006. Rebuild or resurface: Greens must be rebuilt every 15 to 20 years, even those of USGA method construction—or do they? USGA Green Sect. Rec. 44(1):1-6.

Whitlark, B. and N. Hummel. 2018. Rootzone compatibility testing for putting green resurfacing, expansion, and recontouring. USGA Green Sect. Rec. 56(23):1-8.

Wu, L., I. Till-Bottraud, and A. Torres. 1987. Genetic differentiation in temperature-enforced seed dormancy among golf course populations of *Poa annua* L. New Phytol. 107:623-631.

CHAPTER 2: THE EFFECTS OF DAZOMET DOSAGE ON ANNUAL BLUEGRASS SEED VIABILITY

ABSTRACT

Most concerning to turfgrass managers is annual bluegrass *(Poa annua*) infestation in creeping bentgrass putting greens. At one time, methyl bromide was the most used soil sterilant in turf systems, but it has been banned with limited allocation of restricted use permits for economically important yet vulnerable commodities such as fruits and vegetables. Thus, alternatives must be investigated to curtail weed seed soil bank accumulations. Dazomet is one such fumigant labeled to target annual bluegrass populations in turfgrass systems. Critical research questions related to dazomet efficacy pertain to how soil texture, and depth of seed bank affect efficacy as well as which application rate is most effective within a soil. Glass jars (0.945 L) were filled with two soil types, a sandy loam and sandy clay loam, and annual bluegrass seeds (placed in a nylon mesh bag to ease retrieval) were buried at depths of 3.0 cm and 6.0 cm. Dazomet treatments consisted of the following: 294, 439, 588 kg•ha^{-1}, a negative control (no fumigation), and a positive control (autoclaved seed). Irrigation was applied at an equivalent rate of 2.54 cm•d^{-1} of water to activate and incorporate the fumigant within the soil profile. All treatments were then incubated at ~25° C for 2 weeks in darkness. Afterward, the nylon-bagged seeds were recovered, and 2,400 seeds were germinated in paper-blotter-lined petri dishes to determine the effects of dazomet on seed mortality. Regardless of the rate of fumigation, seedling emergence was suppressed in both soil types and at both seed placement depths. The simulated high-barrier tarping and standard water sealing methods increased dazomet efficacy against seed germination and seedling emergence. The date suggests that dazomet is

a highly viable fumigant to control annual bluegrass seed infestations in turfgrass systems.

INTRODUCTION

The annual bluegrass seed bank is a major concern in both agroecosystems and turfgrass systems. Currently, turfgrass managers are perplexed as to the methods of controlling weed seed infestation in putting greens because of the ban on methyl bromide At one time, methyl bromide was the most used soil sterilant in turf systems, but now, it is limited to restricted use permits for economically important yet vulnerable commodities such as fruits and vegetables (U.S. Environmental Protection Agency, 2016). Alternatives are needed to curtail weed seed soil bank accumulations. Although soil fumigation is essential to increasing crop quality and yield, environmental issues are at the forefront with eco-friendly, integrated pest management strategies, i.e., cultural practices alone or in combination with reduced pesticide rates, gradually gaining popularity as alternatives to chemical pesticide use in target sites. Particularly, as golf courses undertake renovation projects due to aging, functionally deficient putting greens (Jones, 2019). More so they also want to minimize expenses associated with disease management. It more costly to maintain an annual bluegrass-dominated putting green than a creeping bentgrass putting green, i.e., seasonal fungicide inputs being close to $22,000 and $18,000, respectively (Bigelow and Tudor, 2012).

Now, the fumigant of choice for golf course renovation projects, methyl bromide has been phased out of agricultural systems by the U.S. Environmental Protection Agency (EPA) because it is an ozone-depleting substance (ODS). Thus, creating a quandary as to the availability of effective yet economically viable, alternative soil sterilization methods with only six-EPA registered fumigants available for use. Choices are limited in this age of environmental sustainability, but research on the efficacy of dazomet has shown that adequate control of various soil pests could be achieved which could make it a viable option for turfgrass systems in lieu of methyl bromide (Branham et al., 2004; Bravo et al., 2018; Park and Landschoot, 2003). Available in a granular form and relatively easy to apply, it is one of only two fumigants labeled to target annual bluegrass populations in turfgrass systems. Just incorporate (tillage) and liberally water into soil, and most target pests succumb to the devastating exposure effects of gaseous methyl isothiocyanate (MITC). But great care must be taken to prevent atmospheric losses from this edaphic environment. Thus, application sites are so often tarped with polyethylene sheets of varying thicknesses and permeability thresholds to reduce MITC losses and increase efficacy (Park and Landschoot, 2003). However, some research on dazomet efficacy observed acceptable control of grassy weeds with reduced application rates in uncovered treatment plots (Bravo et al., 2018; Jeffries et al., 2017; Park and Landschoot, 2003; Simpson et al., 2010). So often the seed bank at depth poses the greatest risk for annual bluegrass invasion after renovation (Branham et al, 2004). So that perhaps, a study could be designed to evaluate the effects of different dazomet dosages, seed placement depths, and soil types on annual bluegrass emergence; and further test the hypothesis that applying higher dosages to a coarse-texture soil will affect the seed bank more so than lower dosages in fine-textured soils with deeply buried seed.

MATERIALS AND METHODS

Annual bluegrass seeds were harvested from plants grown in the Plant, Soil, and Microbial Sciences greenhouse facility at Michigan State University (MSU) in East Lansing, MI. Also, two soil types were taken from field sites near the Hancock Turfgrass

Research Center, East Lansing: Colwood-Brookston loam being fine-loamy, mixed, active, mesic Typic Endoaquolls; and Capac loam being fine-loamy, mixed, mesic Aquic Glossudalfs. After threshing and winnowing, approximately 220 seeds (~0.04 g) were enclosed in a nylon mesh bag and each placed into 80 glass jars [8.5-cm-inside diameter by 17.0-cm-deep (950-ml)] at specified seed placement depths of 3.0 or 6.0 cm, the jars then being backfilled level to a 11.5-cm total soil depth. Soil surface area equated to approximately 0.005 m^2. Experimental soils were sieved through a 2.0-mm standard soil sieve, taking care to preserve soil aggregation, and approximately 923 g of which were poured loosely into each jar with no additional tamping. These treatment jars were then allowed to equilibrate at 25.5 °C for one day before seeds were placed into the soil treatments.

Dazomet treatments consisted of the following: 294, 439, and 588 kg•ha^{-1}, a negative control (no fumigation), and a positive control (seed and soil autoclaved at 121 °C for a 1-hour duration). Irrigation was applied at an equivalent rate of 2.54 cm•d^{-1} of water to activate and incorporate the fumigant within the soil profile (as gaseous formation MITC) of each treatment combination and immediately capped with a metal lid. The treated jars were subjected to a 21-d fumigation exposure period in a controlled-environment growth chamber as described by Merewitz et al. (2011) with conditions set to maintain a 500 µmol m^{-2} s^{-1} photosynthetic photon flux density, day and night temperatures of 25 °C and 20 °C, respectively, but regulated at 67% relative humidity with a 14-h photoperiod. After the prescribed exposure period, all eighty nylon-bagged annual bluegrass seeds were recovered and ambient amounts of viable seeds in the study soils were determined by a warm germination test which consisted of 2,400 seeds propagated under moist conditions in blotter-paper-lined petri dishes. Four replications at 30 seeds•petri dish^{-1} were placed into a controlled-environment growth chamber as described previously. The test duration was 20 d as prescribed for the final count of emerged seedlings. Seeds and seedlings were categorized into normal seedlings, abnormal seedlings, dead seeds, fresh non-germinated and hard seeds. Only normal seedlings were counted in the percentage germination as characterized by a well-developed root system, well-developed and intact hypocotyl, intact plumule with well-developed green leaf, and one cotyledon. Exceptions were made for slightly defective seedlings as affected by fungi and bacteria provided, a given display of vigor and balance in development of essential structures.

Germination results were expressed as percentage by number where the rate is the average number of seeds that germinate in the 20-d test duration with the formula of germination (%) = $\left[\frac{\Sigma_{(n+1)/\text{no. reps}}}{\text{no. seeds}}\right] \times 100$. The experimental design was a completely randomized design with four replications. Data analysis was conducted using PROC GLIMMIX in SAS (version 9.4, SAS Institute, Cary, NC). Percentage seed germination data calculated per experimental unit were subjected to analysis of variance and non-linear regression analysis where the following was contrived: $y = \mu + dazomet\ (dt) + seed\ placement\ depth\ (sp) + soil\ type (st) + (d\ x\ sp) + (d\ x\ st) + (sp\ x\ st) + (d\ x\ sp\ x\ st) + rep(st) + e$. Such that a statistical model for the analysis consisted random effects of soil type (blocking factor) and fixed effects of dazomet dose and seed placement depth along with their interactions. Normality and equal variance assumptions have been checked using normal probability plots and side-by-side box plots, respectively. When the main effects were found to be statistically significant, they were examined using mean separations among the cell means. Statistical tests were conducted at 0.05 level of probability. Mean separations were performed based on Fisher's least significant difference (LSD) (Ott and Longnecker, 2001).

RESULTS AND DISCUSSION

Results of main effect test for seedling emergence, or percentage germination at 20 days after seeding (DAS) are presented in Table 7. Significant differences were only observed among dazomet dose treatments. In both trials in 2019 (initiated 21 Aug. and replicated 9 Nov.), all dazomet application rates suppressed annual bluegrass seedling emergence regardless of the soil type and seed placement depth (Table 8). The thin bracts enclosing the caryopsis (with a thin pericarp) made it easy to observe the effects of fumigation and high heat on the soil seed bank (Figure 3). The fumigated and autoclaved seeds had darkened embryos compared to the seeds in the negative control (no fumigation) which retained the translucently tan, or buff coloration that is a characteristic of healthy annual bluegrass seed (Beard, 1973).

Table 7. Analysis of variance results for annual bluegrass emergence following dazomet treatment and 20 d after seeding in blotter-paper-lined petri dishes in 2019 at East Lansing, MI.

Source of variation[z]	df	P > F[y]	
		Trial I[x]	Trial II
Dazomet treatment (DT)	4	<0.0001*	<0.0001*
Seed placement depth (SP)	1	0.9840	0.8561
DT x SP	4	1.0000	0.9870
Soil type (ST)	1	0.9046	0.8670
DT x ST	4	0.9943	0.9870
SP x ST	1	0.9701	0.8561
DT x SP x ST	4	1.0000	0.9870

[z] Dazomet treatments were 294, 439, and 588 kg•ha^{-1}, seed placement depths of 3 cm and 6 cm with soil types being a sandy clay loam and loamy sand.

[y] Random-block factor effects analysis of variance model in SAS (version 9.4; SAS Institute, Cary, NC) at *$P \leq 0.05$. Germination was based on the number of emerged seedlings per 30 seeds in each replication.

[x] The study was initiated on 21 Aug. and replicated 9 Nov.

Table 8. Effects of dazomet treatment on annual bluegrass emergence 20 d after seeding in blotter-paper-lined petri dishes in 2019 at East Lansing, MI.

Dazomet treatment ($kg \cdot ha^{-1}$)[z]	Mean germination (%)[y]	
	Trial I[x]	Trial II
294	0.0 b[w]	0.0 b
439	0.0 b	0.0 b
588	0.0 b	0.0 b
Positive control	0.0 b	0.0 b
No fumigation	84.2 a	98.8 a
LSD	3.7	0.5

[z] Dazomet treatments were 294, 439, and 588 $kg \cdot ha^{-1}$,seed placement depths of 3 cm and 6 cm with soil types being a sandy clay loam and loamy sand. Positive control seeds were autoclaved at 121 °C.

[y] Germination results were expressed as percentage by number where the rate is the average number of seeds that germinate in the 20-d duration.

[x] The study was initiated on 21 Aug. and replicated 9 Nov.

[w] Mean values within columns separated in accord to Fisher's least significant difference (LSD) at $P \leq 0.05$.

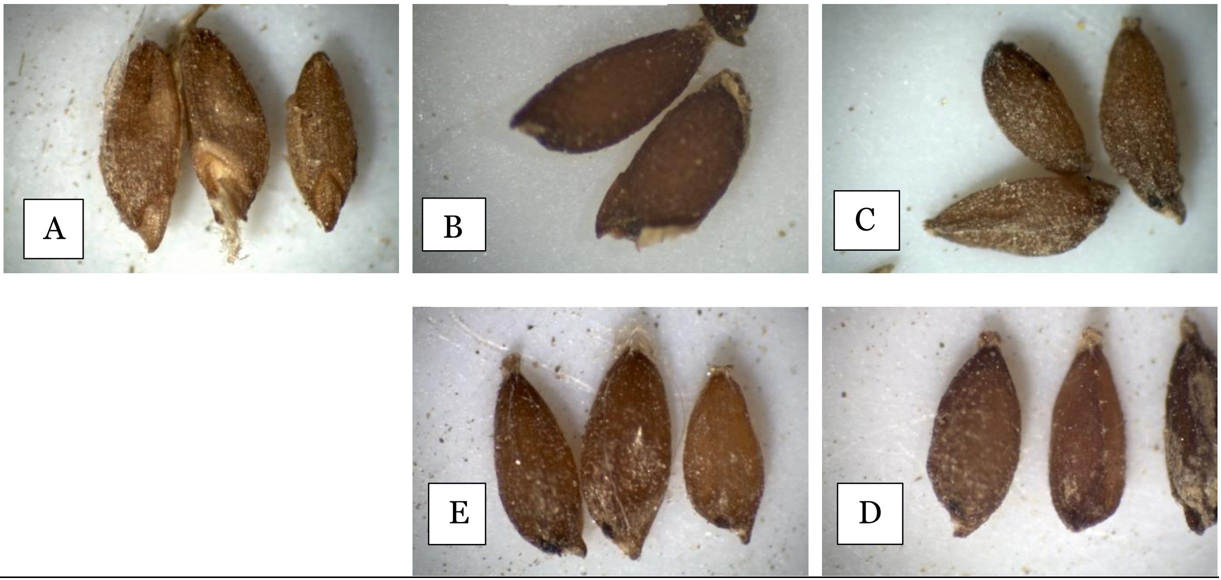

Figure 2. Photos showing the effects of dazomet treatments on annual bluegrass seed. Clockwise from top left, no fumigation (A), positive control (B) was autoclaved at 121 °C, and dosages of 294 (C), 439 (D), and 588 (E) kg ha^{-1}. Seed size at ~2.0 mm lengthwise in 2019 at East Lansing.

CONCLUSIONS

The simulated high-barrier tarping and standard water sealing methods increased dazomet efficacy against seed germination and seedling emergence for all dosages regardless of soil type and seed placement depth. Therefore, it may be reasonable to assume that dazomet is a viable fumigant for annual bluegrass control in turfgrass systems.

REFERENCES

REFERENCES

Beard, J.B., P.E. Rieke, A.J. Turgeon, and J.M. Vargas, Jr. 1978. Annual bluegrass (*Poa annua* L.): Description, adaption, culture, and control. Agr. Expt. Sta. Res. Rpt. Michigan State Univ. East Lansing, MI.

Beard, J.B. 1973. Turfgrass: Science and Culture. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Branham, B.E., G.A. Hardebeck, J.W. Meyer, and Z.J. Reicher. 2004. Turfgrass renovation using dazomet to control the *Poa annua* L. soil seed bank. HortScience. 39:1763-1767.

Bravo, J.S., T.O. Green, J.R. Crum, J.N. Rogers, S. Kravchenko, and C.A. Silcox. 2018. Evaluating the efficacy of dazomet for the control of annual bluegrass seed germination in renovated turf surfaces. HortTechnology. 28:1-4.

Bigelow, C. and W.T. Tudor. 2012. Economic analysis of creeping bentgrass and annual bluegrass maintenance. Golf Course Mgt. 80(10):76-78, 80, 82, 84, 86, 88, 90-93.

Jeffries, M.D., T.W. Gannon, W.C. Reynolds, F.H. Yelverton, and C.A. Silcox. 2017. Herbicide applications and incorporation methods affect dazomet efficacy on bermudagrass. HortTechnology. 27:24-29.

Jones, P. 2019. Parting shots: Futurama. Golf Course Ind. 51(1):82.

Merewitz, E.B., T. Gianfagna, and B. Huang. 2011. Photosynthesis, water use, and root viability under water stress as affected by expression of *SAG12-ipt* controlling cytokinin synthesis in *Agrostis stolonifera*. J. Expt. Bot. 62:383-395.

Ott, R.M. and M. Longnecker. 2001. An Introduction to Statistical Methods and Data Analysis, 5th ed. Duxbury, Pacific Grove, CA.

Park, B.S. and P.J. Landschoot. 2003. Effects of dazomet on annual bluegrass emergence and creeping bentgrass establishment in turf maintained as a golf course fairway. Crop Sci. 43:1387-1394.

Simpson, C.R., S.D. Nelson, J.E. Stratmann, and H.A. Ajwa. 2010. Surface water seal application to minimize volatilization loss of methyl isothiocyanate from soil columns. Pest Mgt. Sci. 66:686-692.

U.S. Environmental Protection Agency. 2016. Protection of stratospheric ozone: 2016 critical use exemption from the phase-out of methyl bromide.