THE EFFECT OF DAZOMET ON ACCUMULATED ANNUAL BLUEGRASS SEED AND NEWLY SEEDED CREEPING BENTGRASS

By

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ABSTRACT

THE EFFECT OF DAZOMET ON ACCUMULATED ANNUAL BLUEGRASS SEED AND NEWLY SEEDED CREEPING BENTGRASS

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In the summers of 2016 and 2017, multiple field experiments were conducted at the Hancock Turfgrass Research Center (HTRC) (Michigan State University, East Lansing, MI) to examine efficacy and post-treatment seeding effects of dazomet on renovated turf surfaces. Two experimental sites were used; a simulated golf course fairway and golf course putting green. This study consisted of two factors. The first factor, dazomet rate, ranged from 65 lb/acre to 525 lb/A. The second factor, re-seeding interval, consisted of 4 levels: 6, 9, 11 (13 in 2017) and 15 days after dazomet treatment. Dazomet was applied and incorporated with 1 inch of irrigation. Fairway height plots were sealed using subsequent irrigation while the putting green experiment was sealed with a plastic cover. All plots were re-seeded using 1 lb/M 'Pure Distinction' creeping bentgrass (CBG). Data was collected on the number of annual bluegrass plants (ABG) and CBG plants that germinated as well as the percent area covered by CBG and percent area unaffected by the dazomet treatment. Fairway height results showed no negative residual effects on the newly seeded CBG. Control of ABG in fairway height was not considered sufficient, likely due to the lack of an impermeable cover and also due to the incorporation method. The greens height results also suggested no substantial effects on seeded CBG regardless of rate or seeding interval. Greens height data showed desirable control of annual bluegrass, further solidifying the essential function of an impermeable cover.

To my fiancé, Danielle and my parents, Mario and Carrie.
Thank you for your love and support, always.

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LITERATURE REVIEW

In a golf course setting, the putting green is the most intensively managed area, with the most dollars spent per acre (Turgeon, 1991). Golfers expect the putting green to be in pristine playing condition at all times. Greens are often mowed at heights of 0.150 inches and below, they will receive multiple applications of fertilizer, herbicide and fungicides in order to promote health and prevent disease. Golf course fairways are similar to putting greens, however they usually receive less chemical applications and are mowed around 0.5 inches and below. (Beard, 1982). To make these management practice easiest and most effective for superintendents, a single species of turfgrass is desirable. Creeping bentgrass (*Agrostis stolonifera*) is one of the most common species used for golf turf surfaces in temperate regions, however often times creeping bentgrass is susceptible to pressure from annual bluegrass (Warnke, 2003). This leaves the superintendent with multiple species of grass to manage: both an agronomic headache and an eyesore to golfers.

Annual bluegrass was previously known as a challenging turfgrass species across the entire country (Beard et al., 1978). It is now considered desirable in some settings as management practices have evolved, and being a prolific seeding plant, annual bluegrass has built a substantial seedbank among many golf courses (Toler et al., 2007). Approximately 80% of viable annual bluegrass seed can be found in the top 2 inches of the soil profile (Branham et al., 2004). The annual subspecies (Poa annua v. annua), common in warm-climates is less threatening, but perennial biotypes (Poa annua v. reptans) thrive in cool climatic regions and are more difficult to manage (Vargas and Turgeon, 2003).

Renovations of turf surfaces are a common practice following excessive wear or simply as a process to upgrade the playing conditions of an area (Park and Landschoot, 2003). The initial step in a turf surface renovation involves the removal of existing material and often times a complete sterilization of the remaining soil in order to provide the grower with a "blank slate." This process needs to be completed without compromising the original design and undulations of the existing surfaces. Methyl bromide (MB) had long been the preferred choice for this sterilization process due to its ability to effectively suppress weeds as well as soil borne fungi and nematodes in turfgrass (Unruh et al., 2002). Methyl bromide was a common choice not only for turfgrass, but for many agricultural commodities as well. Formerly, MB was the third most commonly used pesticide in the U.S. (22 to 26 million kg), applications have since been significantly reduced to 1-3 million kg (Aspelin, 1997; Atwood and Paisley-Jones, 2017). This decline in usage can be directly related to MB being included as a Class I ozone-depleting substance under the Montreal Protocol. After this classification, MB began to be entirely phased-out of the market (UNEP, 2012).

Dazomet is the only available fumigant that has proven capable of controlling germination of weed seeds present in an existing turfgrass system and is the only restricted use pesticide (RUP) fumigant labeled to control annual bluegrass (Poa annua L.) seed germination (USEPA, 2005). Dazomet is produced as a fine granular formulation and once applied and incorporated, it will hydrolyze to form Methyl Isothiocyanate gas (MITC), exterminating all existing organisms within the soil (McClellan, 2009). Notably, dazomet is easier to apply than traditional liquid fumigants and can be applied by turf managers without needing to contract the job to an outside party.

When applying a soil sterilant, a tarp is usually used to seal the soil surface and prevent the gas from volatilizing into the atmosphere (Park and Landschoot, 2001). This method has been proved effective through many studies and is easily accomplished in a green-height setting where the area covered is relatively small. A problem arises when fairway-height turf is considered for renovation. Often times each fairway is greater than an acre in size, making the task of covering them essentially both financially and physically impossible. Dazomet has been used previously without a cover in agricultural settings where it was tilled into the surface as opposed to watered (Juzwik et al., 1997). Conversely, fairways cannot be cultivated as this would disrupt the delicate undulations that make up the unique architecture of the course. Thus, a method is needed to effectively apply dazomet in order to achieve desired results in these large area settings when neither a tarp nor cultivation is a valid option.

In previous studies, researchers showed that plots covered with a plastic tarp had the lowest annual bluegrass seedling counts regardless of the rate applied (Calhoun and Branham, 1995; Park and Landschoot, 2001). Studies have also shown that when combined with a form of tillage, dazomet can be an effective sterilant (Askew et al., 2004). However, tillage is not a practical option when renovating sensitive turf areas with many undulations, therefore a less intrusive method of incorporation is necessary (Hardebeck et al., 2001; Jeffries et al. 2017). Dazomet has also been formerly studied in combination with other chemistries; however, this was not in attempt to control annual bluegrass, rather warm season weed species (Unruh et al., 2002). Additionally, efficacy of dazomet has been tested by adding it to root zone mix prior to initial seeding and multiple weed species were ultimately controlled by this mixture (Brecke et al., 2005). Two previous studies have concluded that when dazomet is applied at a rate of 350 lb/A or greater and then re-seeded 3 days after treatment, there was no residual effects on germination (Park and Landschoot, 2003; Branham et al., 2004).

In 2015, researchers at Michigan State University studied multiple parameters of dazomet including: rate, covering procedure, soil type and soil bed preparation. This research solidified that when a tarp cover is utilized, regardless of application rate, dazomet effectively controls annual bluegrass seed germination. Furthermore, a trend was seen in plots that had existing material removed and also had a sand cap built up from topdressing. These areas showed on average better control of annual bluegrass seed germination, most likely due to the elimination of many viable seeds prior to treatment (Bravo et al., 2018).

In this study, we aimed to 1) determine effective application rates of dazomet to control annual bluegrass seed germination as well as 2) determine if there would be any residual effects of this fumigant on newly seeded creeping bentgrass. We conducted this study on a simulated golf course green research plot where tarp covers were utilized and also in a simulated golf course fairway plot where no tarp covering was used. Tarping is seen as a practical exercise for greens, but not necessarily for fairways. Multiple rates ranging from 65 lbs/A up to 525 lbs/A were used in both settings in order to determine the most effective, and rates reflected the current label recommendations for these settings. Following dazomet application, a variety of seeding intervals were used in order to determine potential residual effects, either positive or negative, on juvenile ‘Pure Distinction’ creeping bentgrass.

CHAPTER ONE

The Effect of Dazomet on Annual Bluegrass and Newly Seeded Creeping Bentgrass in Golf Course Fairways

Introduction

With methyl bromide (MB) no longer being a legal soil sterilization method, golf courses were left searching for an alternative soil sterilant. The primary product in line to take the place of MB is dazomet. In the summers of 2016 and 2017, a field experiment was conducted at the Hancock Turfgrass Research Center (HTRC) (Michigan State University, East Lansing, MI) to examine efficacy and post-treatment seeding effects of dazomet on renovated fairway height turf surfaces. Research was needed to test the hypothesis that previous findings that showed no residual effects on creeping bentgrass germination when seeded within the product label specified time (Park and Landschoot, 2003; Branham et al., 2004). The goals of this study were to 1) determine a rate of dazomet optimal for suppressing annual bluegrass seed germination and 2) to test the hypothesis that there would be no residual effects on newly seeded creeping bentgrass.

Materials and Methods

The 2000 sq. ft. experimental site was an approximately 15-year-old, experimental mixed-stand, comprised of 60% creeping bentgrass *(Agrostis stolonifera)* and 40% annual bluegrass (*Poa annua*). The native soil of this site is a Capac loam (Fine-loamy, mixed, mesic Aquic Glossudalfs) with a bulk density of 1.5 g/cm^3, a pH of 6.6 and 2.5% w/w organic matter on average (Soil Survey, 2018). This was a simulated golf fairway mowed at 0.5 inch and maintained with a fertility program similar to that of a fairway. Individual plots measured 2 x 4 ft., surrounding each individual plot was a border measuring 1.5 ft.; previous studies have proven this border width to be suitable in suppressing lateral movement of Methyl Isothiocyanate gas (Jefferies et al., 2017).

This study was a randomized complete block design with two factors and four replications. The first factor, dazomet rate, included four levels: 131 lb/acre, 262 lb/acre, 525 lb/acre and a non-dazomet control. The second factor, re-seeding interval, also consisted of 4 levels. In 2016, the initial dazomet application was made on 24 June, the following applications were made on 28 June, 30 June and then 3 July. Seeding then took place on 9 July which gave four re-seeding intervals of 6, 9, 11 and 15 days after treatment (DAT). In 2017, the initial dazomet application was made on 27 June, the following three applications were made on 29 June, 3 July and finally 6 July. These dates gave four re-seeding intervals of 6, 9, 13, and 15 DAT. The 2017 trial was seeded on 12 July (Table 1). 'Pure Distinction' (Tee-2-Green, Hubbard, OR) creeping bentgrass was sown at a rate of 1 lb/M.

Site Preparation

Prior to dazomet application, glyphosate was applied to the existing plot surface and then that application was followed by aggressive cultivation. The glyphosate was applied once (16 June 2016 and 19 June 2017) as a 5% (v/v) spray solution using a carbon dioxide-supplied backpack sprayer, calibrated to apply 45 gal/acre. The cultivation took place seven days after the glyphosate application and included a vertical-cut set at approximately 0.125-inch depth (Vacu-Cutter; True-Surface, Moscow Mills, MO) and a core cultivation with an aerator (ProCore 648; Toro, Bloomington, MN) using 0.5-inch hollow tines at 2 x 2-inch spacing with a 2-inch depth for one pass.

Table 1. Application dates for dazomet in the 2016 and 2017 summer field trials. Staggered application dates allowed for a simulation of a multitude of seeding intervals following application to exam potential residual effects. Michigan State University, East Lansing, MI.

Year	First Application	Second Application	Third Application	Fourth Application	Seeding Day
2016	24 June 15 DAT*	28 June 11 DAT	30 June 9 DAT	3 July 6 DAT	9 July
2017	27 June 15 DAT	29 June 11 DAT	3 July 9 DAT	6 July 6 DAT	12 July

***DAT – the number of days after dazomet treatment that seeding took place**

Following the core cultivation, all cores and material were removed from the experimental site.

Experimental Procedure

All dazomet treatments were individually weighed and bagged using the above rates of 131 lb/acre, 262 lb/acre and 525 lb/acre, prior to application day. All treatments were applied using a shaker bottle to individual plots. The dazomet was incorporated into the soil with 1 inch of irrigation immediately following the application. Irrigation was used in the three days following application in order to keep the surface moist and act as a barrier to keep the gas from escaping. Irrigation rates for those 3 days were: 0.5 inch, 0.25 inch, 0.125 inch, respectively. Irrigation was applied using a hand operated sprayer, which the applicator used in conjunction with a hand-held timer to distribute the desired amount. Prior to the start of this experiment, the irrigation method was calibrated using a 5 gal. bucket and timer. 5 gal. was the amount of water needed per plot to achieve 1 inch of irrigation, so three trials were conducted measuring the amount of time required to fill the bucket to 5 gal. The average of these three trials, 3 minutes and 48 seconds, was the base time used to apply water to each plot during the experiment.

Prior to seeding, all plots were backfilled with 0.35 ft^3 per plot of topdressing sand in order to fill voids of material that was removed during the cultivation process. This amount was calculated to evenly fill all aerification holes, and allowed for a nearly smooth surface. In an effort to ensure consistent environmental conditions, all plots were seeded on the same day. Thus, application days were staggered using the intervals mentioned above (Table 1). Immediately before seeding, an 18-24-12 starter fertilizer was applied to all plots at a rate of 1 lb/1000 ft^2 (M) of P_2O_5. One half of each plot was then seeded using 1 lb/M of ‘Pure Distinction’ creeping bentgrass. The seed was pre-weighed and bagged, then applied using a shaker bottle. Only one half of each plot was seeded. The seeded half was used to evaluate creeping bentgrass germination while the unseeded half was used to evaluate annual bluegrass germination. The entire experimental area was irrigated daily with overhead irrigation following this seeding in order to aid in creeping bentgrass seed germination. An important note on change in irrigation schedule from year one to year two: In year one (2016), 0.1 inch of water was applied one time daily, while in year two (2017), 0.1 inch of water was applied four times daily.

Data Collection and Analysis

Annual bluegrass counts were taken 16 and 54 (2016) days after seeding (DAS), then 13 and 56 DAS (2017). Creeping bentgrass counts were taken 54 (2016) DAS and 56 (2017) DAS. All plant counts were done manually, using a line intersecting grid count (Hathaway, 2006). This called for the use of a 1 x 1-ft grid, which had 144 intersections. The grid was placed near the center of each individual plot and each plant that touched one of the 144 intersections was counted. Percent area covered by creeping bentgrass was a visual, quantitative estimate. Collected data was organized into a digital workbook (Excel; Microsoft Corporation, Redmond, WA) and statistical analysis software (SAS version 9.4; SAS Institute, Cary, NC) was utilized for the analysis. Year was analyzed as an independent factor with all measured factors and found to be statistically significant, therefore data were analyzed independently for each year. Analysis of variance (ANOVA) was used to determine significant effects at the $P < 0.05$ level and treatment differences were analyzed using a PROC MIXED function. In the case of a significant effect or interaction, means were separated using Fisher's Least Significant Difference procedure at the 0.05 level of probability.

Results and Discussion

Annual Bluegrass Germination

One of the main objectives of this study was to determine whether dazomet could effectively prevent annual bluegrass from germinating by exterminating the existing seed bank. A significant difference was observed among levels of dazomet rate in both 2016 and 2017 for annual bluegrass germination control (Table 2). At 54 DAS in 2016 and 13 DAS in 2017 there was significantly higher amounts of annual bluegrass plants per square foot in control plots when compared to plots treated with 525 lb/A of dazomet, nearly 3 times more in both years (Table 3). 2016 showed a mean of 88.5 plants in the control plots and 24.8 in the 525 lb/A plots at 54 DAS. In 2017, 13 DAS, there was an average of 7.3 plants in the control plots and only 2.9 plants per square foot in the 525 lb/A plots. Both years showed significantly better control using a rate of 262 lb/A compared again to the control. The control plots had nearly 2 times the amount of annual bluegrass plants per square foot in both years. In 2016 there was again an average of 88.5 plants per square foot in control plots and 52.6 plants on average in the 262 lb/A plots. In 2017, average annual bluegrass plant counts were 7.3 per square foot in the control plot and 4.1 plants on average in the 262 lb/A plots. It is crucial to indicate that although some treatments showed significant efficacy against annual bluegrass germination, no treatments showed ideal control or zero plants per square foot.

Table 2. Analysis of variance (ANOVA) results for fairway height turf from a multitude of dazomet rates and seeding intervals in 2016 and 2017. Michigan State University, East Lansing, MI. Numbers represent calculated p-values.

	Annual Bluegrass Germination				Creeping Bentgrass Germination		Percent Plant Cover	
Source of variation	**2016 16 das[z]**	**2016 54 das**	**2017 13 das**	**2017 56 das**	**2016 54 das**	**2017 56 das**	**2016 48 das**	**2017 40 das**
Rate	**0.1475**	**0.0014***	**0.0074***	**0.7295**	**0.1321**	**0.1500**	**0.0010***	**0.0187***
Seeding	**0.6484**	**0.3669**	**0.3859**	**0.4932**	**0.9486**	**0.5774**	**0.2794**	**0.2135**
Rate x Seeding	**0.8315**	**0.4539**	**0.5693**	**0.1536**	**0.4421**	**0.6273**	**0.2828**	**0.6299**

*** Denotes significance at the 0.05 probability level.**

[z] das – represents the number of days that have elapsed following creeping bentgrass seeding

Table 3. Effects of dazomet and creeping bentgrass seeding intervals on fairway height plant germination and coverage in 2016 and 2017. Michigan State University, East Lansing, MI.

	Annual Bluegrass Germination (plants per ft^2)		Creeping Bentgrass Germination (plants per ft^2)		Percent Plant Cover (%)	
Dazomet Rate	2016 54 das	2017 13 das	2016 54 das	2017 56 das	2016 48 das	2017 40 das
Control	89 a	7 a	4 a	133 a	60 a	81 a
131 lb/A	68 ab	7 a	4 a	125 a	45 ab	71 b
262 lb/A	53 b	4 b	8 a	135 a	32 bc	76 ab
525 lb/A	25 c	3 b	9 a	142 a	18 c	84 a
Seeding Interval	2016 54 das	2017 13 das	2016 54 das	2017 56 das	2016 48 das	2017 40 das
6 dat[z]	58 a	5 a	5 a	134 a	33 a	80 a
9 dat	68 a	5 a	7 a	135 a	41 a	81 a
11 (13) dat	48 a	5 a	6 a	139 a	37 a	78 a
15 dat	59 a	6 a	7 a	128 a	44 a	73 a

*Means followed by similar letters have no significant difference at the 0.05 probability level. Separated by Fishers LSD

[z] dat – the number of days following dazomet treatment before seeding took place

These results correlate to past research that suggests without a tarp cover, dazomet exhibits limited control of annual bluegrass, even at high rates (Branham et al., 2004). It was speculated this may be due to environmental factors such as high wind that contributed to a quick loss of MITC gas. Furthermore, it is important to restate that all dazomet treatments were incorporated with water and as previously shown this method does not provide consistent control compared to physically incorporated treatments (Jefferies et al., 2017).

Creeping Bentgrass Germination

No significant differences were observed among treatments for creeping bentgrass germination in both 2016 and 2017 (Table 2). The rate of dazomet applied and interval after application before creeping bentgrass was seeded had no effect on the germination of creeping bentgrass. In 2017, a large increase in creeping bentgrass plants per square foot was observed across all treatments as compared to 2016, but still no significant differences were observed among treatments (Table 3). These results agree with previous work that showed no negative effects when creeping bentgrass was seeded 3 days after a dazomet treatment of nearly 350 lb/A (Park and Landschoot, 2003; Branham et al., 2004). Average creeping bentgrass counts in 2016 ranged from about 4 – 9 plants per square foot, independent of seeding interval and rate of dazomet used. These same averages jumped to a range of 125 – 142 plants per square foot in 2017. Creeping bentgrass numbers increased from about 5% coverage (7 plants per square foot) to nearly 100% coverage (144 plants per square foot). This jump in germination is likely related to the increase in irrigation applied in 2017. The irrigation regime increased from 0.1 inch daily to 0.4 inch daily.

Summary

Dazomet had no negative residual effects on creeping bentgrass germination, even when applied at the highest amount of 525 lb/A. The results indicated increased control of annual bluegrass germination in plots treated with a high amount (525 lb/A) of dazomet; albeit not with consistent days after seeding for each year, however, the average annual bluegrass counts in these plots would still not be considered acceptable suppression. Further research should push to develop effective use methods for dazomet when an impermeable cover cannot be used.

CHAPTER TWO

The Effect of Dazomet on Annual Bluegrass and Newly Seeded Creeping Bentgrass in Golf Course Putting Greens

Introduction

Putting greens are commonly renovated using a soil sterilant, and the use of this sterilant will likely involve a plastic cover to seal the surface and prevent the gas from volatilizing (Unruh et al., 2002; Park and Landschoot 2001). In the summers of 2016 and 2017, a field experiment was conducted at the Hancock Turfgrass Research Center (HTRC) (Michigan State University, East Lansing, MI) to examine efficacy and post-treatment seeding effects of dazomet on renovated putting green surfaces. The goals of this study were to 1) determine a rate of dazomet to be used with a plastic cover that would be optimal for suppressing annual bluegrass seed germination and to 2) determine if there would be residual effects on newly seeded creeping bentgrass.

Materials and Methods

The experimental site had an 80/20 sand peat root zone and was seeded in 2007 with A4 creeping bentgrass. This was a simulated golf green mowed at 0.130 inch and maintained with a fertility program similar to that of a green. Individual plots measured 2 x 4 ft, surrounding the individual plots was a border measuring 1.5 ft. on each side for tarping; previous studies have proven this border width to be suitable in suppressing lateral movement of Methyl Isothiocyanate gas (Jefferies et al., 2017).

This study was a randomized complete block design with two factors and four replications. The first factor, dazomet rate, included five levels: 65 lb/acre, 131 lb/acre, 196.5 lb/acre, 262 lb/acre, and a non-dazomet control. The second factor, re-seeding interval, also consisted of 4 levels. In 2016, the initial dazomet application was made on 24 June, the following applications were made on 28 June, 30 June and then 3 July. Seeding then took place on 9 July which gave four re-seeding intervals of 6, 9, 11 and 15 days after treatment (DAT). In 2017, the initial dazomet application was made on 27 June, the following three applications were made on 29 June, 3 July and finally 6 July, giving four re-seeding intervals of 6, 9, 13, and 15 DAT (Table 4). The 2017 trial was seeded on 12 July using 'Pure Distinction' creeping bentgrass at a rate of 1 lb/M.

Site Preparation

Prior to dazomet application, glyphosate was applied to the existing plot surface and then that application was followed by aggressive cultivation. The glyphosate was applied once (16 June 2016 and 19 June 2017) as a 5% (v/v) spray solution using a carbon dioxide-supplied backpack sprayer, calibrated to apply 45 gal/acre. The cultivation took place seven days after the glyphosate application and included a vertical-cut set at approximately 0.125-inch depth (Vacu-Cutter; True-Surface, Moscow Mills, MO) and a core cultivation with an aerator (ProCore 648; Toro, Bloomington, MN) using 0.5-inch hollow tines at 2 x 2-inch spacing with a 2-inch depth for one pass. Following this core aerification, all cores and material were removed from the experimental site.

Experimental Procedure

All dazomet treatments were individually weighed and bagged using the above rates of 65 lb/acre, 131 lb/acre, 196.5 lb/acre, 262 lb/acre, prior to application day. All treatments were

Table 4. Application dates for dazomet in the 2016 and 2017 summer field trials. Staggered application dates allowed for a simulation of a multitude of seeding intervals following application to exam potential residual effects. Michigan State University, East Lansing, MI.

Year	First Application	Second Application	Third Application	Fourth Application	Seeding Day
2016	24 June 15 DAT*	28 June 11 DAT	30 June 9 DAT	3 July 6 DAT	9 July
2017	27 June 15 DAT	29 June 11 DAT	3 July 9 DAT	6 July 6 DAT	12 July

***DAT – the number of days after dazomet treatment that seeding took place**

then applied, using a shaker bottle, to individual plots. The dazomet was incorporated into the soil with 1 inch of irrigation immediately following the application. Irrigation was applied using a hand-operated sprayer, which the applicator used in conjunction with a hand-held timer to distribute the desired amount. Prior to the start of this experiment, the irrigation method was calibrated using a 5 gal. bucket and timer. 5 gal. was the amount of water needed per plot to achieve 1 inch of irrigation, so three trials were conducted measuring the amount of time required to fill the bucket to 5 gal. The average of these three trials, 3 minutes and 48 seconds, was the base time used to apply water to each plot during the experiment. Following incorporation and activation, all plots were immediately covered with a 4-mil plastic tarp measuring 3 x 5 ft. The tarps were sealed using the 1.5 ft. strip of sod on the surrounding borders. All tarps were left on for seven days following application and then removed.

Prior to seeding, all plots were backfilled with 0.35 ft^3 per plot of topdressing sand in order to fill voids of material that were removed during the cultivation process. This amount was calculated to evenly fill all aerification holes, and allowed for a nearly smooth surface. In an effort to ensure consistent environmental conditions, all plots were seeded on the same day. Thus, application days were staggered using the intervals mentioned above (Table 4). Immediately before seeding, an 18-24-12 starter fertilizer was applied to all plots at a rate of 1 lb/M of P_2O_5. One half of each plot was then seeded using 1 lb/M of ‘Pure Distinction’ creeping bentgrass. The seed was pre-weighed and bagged, then applied using a shaker bottle. Only one half of each plot was seeded. The seeded half was used to evaluate creeping bentgrass germination, while the unseeded half was used to evaluate annual bluegrass germination. The entire experimental area was irrigated daily with overhead irrigation following this seeding in order to aid in creeping bentgrass seed germination. An important note on change in irrigation schedule from year one to year two: In year one (2016) 0.1 inch of water was applied one time daily, while in year two (2017) 0.1 inch of water was applied four times daily.

Data Collection and Analysis

Percent coverage of creeping bentgrass was recorded 16 and 48 (2016) DAS then 16 and 40 (2017) DAS. Creeping bentgrass counts were taken 5, 24 and 54 DAS (2016) 57 DAS (2017). All plant counts were done manually, using a line intersecting grid count (Hathaway, 2006). This called for the use of a 1 x 1-ft grid, which had 144 intersections. The grid was placed near the center of each individual plot and each plant that touched one of the 144 intersections was counted. Percent area covered by creeping bentgrass was a visual, quantitative measurement. Collected data were organized into a digital workbook (Excel; Microsoft Corporation, Redmond, WA) and statistical analysis software (SAS version 9.4; SAS Institute, Cary, NC) was then utilized for the analysis. Year was analyzed as an independent factor with all measured factors and found to be statistically significant, therefore data were analyzed independently for each year. Analysis of variance (ANOVA) was used to determine significant effects at the $P < 0.05$ level and treatment differences were analyzed using a PROC MIXED function. In the case of a significant effect or interaction, means were separated using Fisher's Least Significant Difference procedure at the 0.05 level of probability.

Results and Discussion

Annual Bluegrass Germination

In the previous studies of dazomet application with the use of an impermeable plastic cover, acceptable control of accumulated annual bluegrass seed was observed (Park and

Landschoot, 2001; Bravo et al., 2018). This study further supports those findings. Both years yielded significant differences for dazomet rate (Table 5). Control plots showed an average of nearly 5 annual bluegrass plants per square foot in 2016 and 3 plants per square foot in 2017 while all plots treated with dazomet had less than 1 plant per square foot on average in both years (Table 6). This is an indication that dazomet could potentially be used at lower rates such as 65 lbs/A and still effectively suppress annual bluegrass seed germination when a plastic cover is used following application; however as previously stated, this low of a rate in this formulation may not cover and treat the entire area effectively.

Creeping Bentgrass Germination

Considering the goal of evaluating potential residual effects on newly seeded creeping bentgrass, past work has shown there to be no negative effects on creeping bentgrass seeded 3 days after a treatment of 350 lbs/A of dazomet (Park and Landschoot, 2003). Statistically, there were significant differences among dazomet rates for number of creeping bentgrass plants counted (Table 5). However, in both years, the control plots did not statistically have more plants than the higher rate (262 lb/acre) treated plots. The difference is seen when comparing the control to the lower rates. In 2016, control plots had 114 plants per square foot and in 2017 control plots had 142 plants per square foot (Table 6).

Table 5. Analysis of variance (ANOVA) results for greens height turf from a multitude of dazomet rates and seeding intervals in 2016 and 2017. Michigan State University, East Lansing, MI. Numbers represent calculated p-values.

	Annual Bluegrass Germination		Creeping Bentgrass Germination		Percent Plant Cover	
Source of variation	**2016 54 das**	**2017 57 das**	**2016 54 das**	**2017 57 das**	**2016 48 das**	**2017 40 das**
Rate	**0.0003***	**<.0001***	**0.0138***	**0.0406***	**0.0130***	**0.0404***
Seeding	**0.5215**	**0.3536**	**0.5468**	**0.0235***	**0.7649**	**0.0857**
Rate x Seeding	**0.5798**	**0.3154**	**0.7478**	**0.5529**	**0.3124**	**0.2808**

*** Denotes significance at the 0.05 probability level.**

[z] das – represents the number of days that have elapsed following creeping bentgrass seeding

Table 6. Effects of dazomet and creeping bentgrass seeding intervals on greens height plant germination and coverage in 2016 and 2017.

Michigan State University, East Lansing, MI.

	Annual Bluegrass Germination (plants per ft^2)		Creeping Bentgrass Germination (plants per ft^2)		Percent Plant Cover (%)	
Dazomet Rate	**2016 54 das**	**2017 57 das**	**2016 54 das**	**2017 57 das**	**2016 48 das**	**2017 40 das**
65 lb/A	**1 b**	**1 b**	**70 b**	**136 b**	**50 b**	**71 b**
131 lb/A	**0 b**	**1 b**	**78 b**	**138 b**	**53 b**	**73 b**
196.5 lb/A	**0 b**	**0 b**	**87 b**	**139 ab**	**55 b**	**75 b**
262 lb/A	**0 b**	**0 b**	**93 ab**	**140 ab**	**56 b**	**75 b**
Control	**5 a**	**3 a**	**114 a**	**142 a**	**73 a**	**83 a**
Seeding Interval	**2016 54 das**	**2017 57 das**	**2016 54 das**	**2017 57 das**	**2016 48 das**	**2017 40 das**
6 dat[z]	**1 a**	**1 a**	**96 a**	**141 a**	**61 a**	**96 a**
9 dat	**2 a**	**1 a**	**84 a**	**142 a**	**56 a**	**84 a**
11 (13) dat	**1 a**	**1 a**	**81 a**	**138 b**	**56 a**	**81 a**
15 dat	**1 a**	**1 a**	**94 a**	**136 b**	**57 a**	**94 a**

***Means followed by similar letters have no significant difference at the 0.05 probability level. Separated by Fishers LSD**

[z] dat – the number of days following dazomet treatment before seeding took place

In relation to percent cover, there was significant difference among rates in both years for percent plant coverage. Control plots had significantly higher percent coverage than all dazomet treated plots. Control plots had around 73 and 83 percent coverage in 2016 and 2017 respectively while lower rate treated plots had roughly 55 and 73 percent coverage, respectively (Table 6). Percent coverage is a visual measurement and therefore is not faultless. Average percent of creeping bentgrass, especially in control plots, could potentially be skewed by competing annual bluegrass blending into the newly seeded plots, hence the title of the measurement “percent plant coverage”.

In 2017 there was also a significant difference among seeding intervals. The plots seeded sooner after treatment (6 and 9 dat) had an average of 141 plants per square foot nearly two months after seeding. In comparison, longer seeding intervals after dazomet treatment (11 and 15 dat) had an average of about 137 plants per square foot (Table 6). This would suggest that shorter seeding intervals are more beneficial for creeping bentgrass as opposed to waiting over a week to re-seed. Previous work has found that in the case of waiting to seed creeping bentgrass following dazomet application, annual bluegrass competes with and hinders germination (Branham et al., 2004), our results would support these findings.

Summary

In both years**,** there were significant differences among unaffected areas, which is likely attributed to the fine granular texture of the chemical. Furthermore, dazomet showed that at all tested rates, it could effectively suppress annual bluegrass seed when a tarp was used following application. Finally, considering bentgrass germination, no substantial differences were seen among treatments to suggest that dazomet would have negative residual effects on a newly seeded creeping bentgrass green.

CONCLUSIONS

In fairway height trials without tarping, the results indicated increased control of annual bluegrass germination in plots treated with a high amount (525 lb/A) of dazomet; albeit not with consistent days after seeding for each year, however, the average annual bluegrass counts in these plots would still not be considered acceptable suppression. There were no negative residual effects when creeping bentgrass was seeded into treated plots. An increase in post seeding irrigation showed increased creeping bentgrass germination in year two of the study; regardless of this, all patterns of efficacy and seeding effects stayed similar to the first year.

The greens height trials showed at all tested rates, dazomet could effectively suppress annual bluegrass seed when a tarp was used following application. Considering bentgrass germination, no substantial differences were seen among treatments to suggest that dazomet would have negative residual effects on a newly seeded creeping bentgrass green.

Further research should be conducted examining use of higher rates of dazomet in non-tarped settings. Considerations should also be made to alter the pre-treatment regime for dazomet in order to increase efficacy. Overall, dazomet can be considered effective in controlling annual bluegrass seed germination when the product label rate is applied and an impermeable cover is used. Finally, there are no concerns of residual effects when re-seeding creeping bentgrass within the label recommended interval.

APPENDIX

Analysis of variance (ANOVA) results for *annual bluegrass count* in greens height turf. MSU Hancock Turfgrass Research Center.					
Source of variation	**2016 – 5 das**	**2016 – 16 das**	**2016 – 54 das**	**2017 – 13 das**	**2017 – 57 das**
Rate	**0**	**0.2270**	**0.0003***	**0**	**<.0001***
Seeding Interval	**0**	**0.2518**	**0.5215**	**0**	**0.3536**
Rate x Seeding Interval	**0**	**0.1695**	**0.5798**	**0**	**0.3154**
*** Denotes significance at the 0.05 probability level**					

Analysis of variance (ANOVA) results for *creeping bentgrass count* in greens height turf. MSU Hancock Turfgrass Research Center.				
Source of variation	2016 – 5 das	2016 – 24 das	2016 – 54 das	2017 – 57 das
Rate	0	0.3106	0.0138*	0.0406*
Seeding Interval	0	0.5558	0.5468	0.0235*
Rate x Seeding Interval	0	0.5980	0.7478	0.5529
* Denotes significance at the 0.05 probability level				

Analysis of variance (ANOVA) results for *percent coverage (CBG)* in greens height turf. MSU Hancock Turfgrass Research Center.				
Source of variation	**2016 – 19 das**	**2016 – 48 das**	**2017 – 16 das**	**2017 – 40 das**
Rate	**0.4698**	**0.0130***	**0.8628**	**0.0404***
Seeding Interval	**0.6347**	**0.7649**	**0.5085**	**0.0857**
Rate x Seeding Interval	**0.5873**	**0.3124**	**0.1367**	**0.2808**
*** Denotes significance at the 0.05 probability level**				

Analysis of variance (ANOVA) results for *percent coverage (CBG)* in fairway height turf. MSU Hancock Turfgrass Research Center.				
Source of variation	**2016 – 19 das**	**2016 – 48 das**	**2017 – 16 das**	**2017 – 40 das**
Rate	**0.2405**	**0.0010***	**0.0825**	**0.0187***
Seeding Interval	**0.7005**	**0.2794**	**0.3495**	**0.2135**
Rate x Seeding Interval	**0.0418***	**0.2828**	**0.3161**	**0.6299**
*** Denotes significance at the 0.05 probability level**				

Analysis of variance (ANOVA) results for *creeping bentgrass count* in fairway height turf. MSU Hancock Turfgrass Research Center.				
Source of variation	**2016 – 5 das**	**2016 – 24 das**	**2016 – 54 das**	**2017 – 56 das**
Rate	**0.1646**	**0.0053***	**0.1321**	**0.1500**
Seeding Interval	**0.7500**	**0.1965**	**0.9486**	**0.5774**
Rate x Seeding Interval	**0.1519**	**0.5243**	**0.4421**	**0.6273**
*** Denotes significance at the 0.05 probability level**				

Analysis of variance (ANOVA) results for *annual bluegrass count* in fairway height turf. MSU Hancock Turfgrass Research Center.					
Source of variation	**2016 – 5 das**	**2016 – 16 das**	**2016 – 54 das**	**2017 – 13 das**	**2017 – 56 das**
Rate	**0.3417**	**0.1475**	**0.0014***	**0.0074***	**0.7295**
Seeding Interval	**0.4519**	**0.6484**	**0.3669**	**0.3859**	**0.4932**
Rate x Seeding Interval	**0.0506**	**0.8315**	**0.4539**	**0.5693**	**0.1536**
*** Denotes significance at the 0.05 probability level**					

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