THE EFFECTS OF METHIOZOLIN RATES AND NITROGEN FERTILITY STRATEGIES FOR ANNUAL BLUEGRASS CONTROL AND CREEPING BENTGRASS SAFETY ON GOLF GREENS

THESIS

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Abstract

Annual bluegrass (Poa annua L.) is considered the most problematic weed on golf greens because of its fecund characteristic, low heat and disease tolerance in the summer, massive seed head reproduction, and bright green color. Methiozolin was initially an herbicide for weed control in crop fields and now is being developed for annual bluegrass control on golf greens. It has shown effectiveness and safety on multiple grass species, including creeping bentgrass (Agrostis stolonifera), kentucky bluegrass (Poa pratensis), and bermudagrass (Cynodon dactylon). As a systemic herbicide, methiozolin is mainly taken up by root absorption and shows limited acropetal movement in the plant. It is recommended that methiozolin be watered in immediately after application. Nitrogen, as one of the essential elements of plants, plays an important role in the lateral growth and chlorophyll formation of creeping bentgrass, which can greatly influence the recovery rate, color, and other quality characteristics of the turfgrass surface. Digital Image Analysis (DIA) is a new method for turfgrass surface quality evaluation. DIA has shown efficiency in data analysis with an equal accuracy as the normalized difference vegetation index (NDVI) and better consistency than visual evaluation method (NTEP).

Two experiments were conducted on the Ohio State University Golf Club practice green and one on a USGA green at the Ohio Turfgrass Foundation Research and Education Facility. The first project on the OSU Golf Club putting green was designed to study the interaction of methiozolin, nitrogen rate and fertilizing frequency on creeping
bentgrass recovery and annual bluegrass suppression/control in the spring with fall only methiozolin treatments and fall/spring methiozolin treatments. The second project consisted of three methiozolin rates and four rates to determine the best combination of spring methiozolin rate and spring nitrogen application strategies that shows best control over annual bluegrass while benefiting creeping bentgrass recovery and safety. The third project at the OSU Research and Education Facility was to study the effects of five nitrogen rates on the lateral growth/recovery and quality of creeping bentgrass with/without methiozolin treatments.

The first project found that there was no significant interaction between methiozolin, nitrogen rates and fertilizing frequency in the spring. Spring methiozolin applications had a negative effect on creeping bentgrass color and recovering rate, but also a subsequent control on annual bluegrass after methiozolin fall treatments. Among all nitrogen strategies, the 24.4 kg N ha\(^{-1}\) every two weeks and the 12.2 kg N ha\(^{-1}\) every week were the best for creeping bentgrass green-up and recovery in the spring of 2014. The second experiment project found that methiozolin rates higher than the protocol rate (0.53 kg a.i. ha\(^{-1}\)) had significant negative effects on annual bluegrass color and significantly more decrease on annual bluegrass population. Both creeping bentgrass and annual bluegrass color increased significantly with higher nitrogen rates and 24.4 kg N ha\(^{-1}\) had significantly more decrease on annual bluegrass population, which means higher nitrogen rates benefits creeping bentgrass more than annual bluegrass under methiozolin.
treatments. The third study found that there was no significant negative effects of
methiozolin on creeping bentgrass color or lateral growth. According to the regression, 
there was a quadratic relation between creeping bentgrass color and time. The lateral 
growth rate of creeping bentgrass was constant through time and was only influenced by 
the nitrogen rate.
Dedicated to my boss, Dr. Street
Acknowledgments

I would like to express my special appreciation and thanks to my advisor, Dr. John Street, you have been a tremendous mentor for me. I would like to thank you for encouraging my research and for allowing me to grow as a research scientist. Your advice on both research as well as on my career have been priceless. I would also like to thank my co-advisor Dr. David Gardner and also Dr. Karl Danneberger for serving as my committee members and offering advice constantly without any hesitation.

I would especially like to thank the Moghu Research Center and Moghu USA, namely Dr. Suk-jin Koo and Mr. Kyung-min Han. Without your endless support with funding, information, and product, the whole project would not have occurred.

A special thanks to my family. Words cannot express how grateful I am to my mother and father for all of the sacrifices that you’ve made for me. I would also like to thank all of my friends who supported me during difficulties, and incited me to strive towards my goal. At the end I would like express appreciation to my beloved one Jing Tseh, who was always my support and provided a home where I could always take a rest when I was struck by life.
Vita

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Introduction

Annual bluegrass (*Poa annua* L.) is considered the most problematic weed on golf greens not only because of its high heat, cold, and disease susceptibility, which causes its decline during the summer and massive kill during harsh winter, but also because of its prolific seed head reproduction and bright green color which interferes with the greens’ putting quality. The fight against annual bluegrass can be dated back to the 1920s with physical removing. After the development of several generations of herbicides, chemical control for annual bluegrass is still not satisfying with accumulated resistance and also the safety of the herbicide on untargeted species.

Developed in 2005 by a South Korean research institution, Methiozolin is an herbicide with a novel mode of action. It was first used as an annual bluegrass and large crabgrass treatment in rice fields, then reformulated to fit the annual bluegrass control purpose on golf course greens and fairways. During practical application and continuing research with this chemical, it has shown its effectiveness for selective control of annual bluegrass and safety on multiple turfgrass species, including creeping bentgrass (*Agrostis stolonifera*), kentucky bluegrass (*Poa pratensis*), perennial ryegrass (*Lolium perenne*), and bermudagrass (*Cynodon dactylon*).
Nitrogen, as one of the essential elements of plants, plays an important role in the lateral growth and chlorophyll formation of the plant, which can greatly influence the recovery rate, color and other quality characteristics of the turfgrass surface. Soil nitrogen is very dynamic in the soil profile, and declines in concentration by leaching or plant uptake. Nitrogen fertilizer application rate and frequency have great influence on maintaining an acceptable nitrogen level in the soil.

However, there is no research studying the interaction between methiozolin and nitrogen. It is still unknown if methiozolin will impair creeping bentgrass color quality or slow creeping bentgrass lateral growth. In addition, also unknown is whether or not extra nitrogen is needed to maintain a quality putting surface or if too much nitrogen will decrease the efficiency of methiozolin on annual bluegrass control. The ultimate goal of this research is to offer more information about the safety of methiozolin on creeping bentgrass putting greens and to integrate this product into the golf course fertilization program.

The research objectives are 1) to determine the interaction between methiozolin and nitrogen rates along with application frequency on annual bluegrass control and creeping bentgrass recovery in the spring after a successful methiozolin fall control; 2) to determine the interaction between methiozolin and nitrogen rates on annual bluegrass control and creeping bentgrass surface quality in the spring; 3) to determine the effects of methiozolin and nitrogen rates on the lateral growth rate of creeping bentgrass in the spring.
After a general introduction of the background and problem situation, this thesis will proceed with literature review of the chemical nature of methiozolin, the importance of nitrogen to turfgrass health and also the potential impact on the emergence of annual bluegrass. Next, three research projects will be discussed in three separate chapters. In each chapter, there will be an introduction to the project, research objectives, methods and materials, data and analysis of results and a conclusion to the project. A general conclusion chapter will discuss the results from all three research projects to answer the general research questions.

Abbreviation:

(OSU) Ohio State University, (NTEP) National Turfgrass Evaluation Program, (WAIT) weeks after initial treatments, (DAIT) days after initial treatments, (PGR) plant growth regulator, (ANOVA) analysis of variance, (LSD) least significant difference, (NDVI) normalized difference vegetation index, (DGCI) dark green color index, (DIA) digital image analysis.
Chapter 1: Literature Review

Annual bluegrass as a problematic weed

Annual bluegrass belongs to the Poaceae family, Pooideae subfamily, Podoae supertribe, Paeae tribe and Poa genus. Annual bluegrass is recognized as one of the most diverse, widespread and noxious weeds in both agricultural fields, landscaping lands, and intensively cultured turf globally (Beard et al., 1978). As early as 1812, William Curtis mentioned annual bluegrass in his book “Grasses of England” as: “common to every quarter of the globe… growing in almost any soil and situation… but liable to be killed by winter's frost, and summer's drought; the first to cover earth made bare… where its seeds being scattered, quickly vegetate, and where it is not overpowered by more luxuriant herbage.” The tolerance of low mowing height and huge soil seed bank make annual bluegrass almost an irresistible invader on putting greens (Peachey et al. 2001). However, its other characteristics, including the light green color, prolific seed head production in spring, courser leaf texture and susceptibility to heat, drought and disease stress which causes death of the plant during summer, makes it an undesired species on greens (Kane and Miller 2003; McCullough et al. 2006; Beard et al. 1978). In addition to those noxious characteristics, heavy seed head production during the whole year and the ability to germinate from the seed bank whenever the environmental conditions are
suitable, makes annual bluegrass even more difficult to control and almost impossible to eliminate.

Annual bluegrass is widely recognized as two subspecies, also commonly described as two biotypes. Actually, the recognition of different biotypes of annual bluegrass dates back to 1957, when Tutin separated the *Poa annua* species into four different breeding races according to their various morphology, germination rate and growth habit, including a clear separation between the annual biotype and the perennial biotype. This idea of differentiation into an annual biotype and a perennial biotype is also embraced by Hovin (1957) and Youngner (1959). There are other opinions about the subspecies of annual bluegrass as well. For example, Timm (1965) proposed that there should be three subspecies of annual bluegrass. However, the most widely accepted concept is *Poa annua* L. var. annua Timm as the annual biotype annual bluegrass, and simplified as *Poa annua* L.; and *Poa annua* L.f. reptans (Hauskins) T. Koyama as the perennial biotype, namely *Poa annua reptans*.

This variation within *Poa annua* is due to the genetic origin of annual bluegrass. As an allotetraploid, annual bluegrass species is believed to originate from a hybrid event between *Poa supina* Schrad and *Poa infirma* H.B.K. Both of *Poa supina* and *Poa infirma* are diploids with a total of 14 chromosomes (Nannfeldt, 1937). A duplication event of the whole set of chromosomes at some point in history made the infertile allodiploid into fertilizable allotetraploid (2n = 4x = 28). *Poa supina* is a perennial species with a prostrate growth habit. On the other hand, *Poa infirma* is an annual species with an upright growth habit and has the ability to set an inflorescence within 60 days after
seedling emergence from the soil (Darmency and Gasquez, 1997). Research by Darmency (1992) shows that within annual bluegrass there is evidence of an estrase isozyme from both of the parents. As a hybrid from both species, annual bluegrass acts as an intermediate between two parental lines. The rapid evolutionary development from the latter hybridization and natural selection pressure have led to many biotypes within annual and perennial subspecies (Vargas and Turgeon, 2004). The huge variability within the species also reflects genetic modification and environmental adaptation.

Despite the differences in life history and morphology, the shared characteristics of both the annual and perennial biotypes include folded vernation, auricle absence, a membranous ligule, a prominent midrib, and a boat-shaped leaf tip. Reproduction characteristics of annual bluegrass include an open panicle inflorescence with perfect flowers. Annual bluegrass is self-pollinated via cleistogamy.

Chemical control of annual bluegrass

Efforts to control annual bluegrass retrospect back to almost 200 years ago. There is a record of George Sinclair in 1825 discussing annual bluegrass control with boiling water or a thick application of salt. The primary control method was limited to physical removal until the 1930s, when lead arsenate was first recorded as a chemical for annual bluegrass control (Sprague and Burton, 1937). Nowadays, chemicals for annual bluegrass control can be classified into two main categories: pre-emergence and post-emergence herbicides.

Pre-emergence herbicides are applied before the emergence of weed seedlings from the soil seed bank and control weeds by providing a chemical barrier within a few
centimeters of the top soil (Turgeon, 1974; Baldwin, 1993). Oxadiazon (3-[2, 4-dichloro-5-(1-methylethoxy)phenyl]-5-(1, 1-dimethyl-1,3,4-oxadiazol-2(3H)-one), dithiopyr (3, 5-pyridinedicarboxthioic acid, 2-(difluoromethyl)-4-(2-methylpropyl)-6-(trifluoromethyl)-S, S-dimethyl easter), dimethyl tetrachloroterephthalate (Dimethyl 2,3,5,6-tetrachlorobenzene-1,4-dicarboxylate), prodiamine (2, 4-dinitro-3-N, 3-N-dipropyl-6-(trifluoromethyl) benzene-1, 3-diamine), bensulide (S-(O, O-diisopropyl phosphorodithioate) easter of N-(2-mercapto) benzenesulfonamide), pendimethalin (N-(1-ethylpropyl)-3, 4-dimethyl-2, 6-dinitrobenzenamine), pronamide (3, 5-dichloro-N-(1, 1-dimethyl-2-propynyl) benzamide), metribuzin (4-Amino-6-(1, 1-dimethylethyl)-3-(methylthio)-1, 2, 4-triazin-5-(4H)-one), benefin (N-butyl-N-ethyl-Â α, α, α-trifluoro-2, 6-dinitro-p-toluidine), and siduron ([1-(2-methylcyclohexyl)-3-phenylurea]) are all pre-emergence herbicides that are able to provide over 80% of annual bluegrass control by preventing recruitment of vegetation from annual bluegrass seeds under experimental conditions (Johnson, 1975; Johnson, 1976; Lewis, 1994). However, inconsistence performance of pre-emergence herbicide for annual bluegrass control is still a problem (Callahan and McDonald 1992). One possible reason for the poor performance of pre-emergence herbicides is a wide range of annual bluegrass seed germination throughout the year (Vargas and Turgeon 2004). The seedling emergence time of annual bluegrass also varies in different climates and areas. Callahan and McDonald (1992) reported in Tennessee, that the emergence of annual bluegrass seedlings starts from mid-to-late November in the fall and early January in the winter. While in Maryland, annual bluegrass seedlings are reported to emerge from September to December, and also a rebound of emergence in the spring (Dernoeden 1998). The variation in annual bluegrass
seedling emergence time at different locations leads to programmatic difficulties in pre-emergence herbicide application scheduling and control efficiency.

Post-emergence herbicides control weeds after their emergence, by offering a certain level of toxicity to the target and controls selectively. The best time for efficient control is at the young stage or when the weed is actively growing (Camacho and Moshier, 1991). Selective post-emergence herbicides for annual bluegrass control include trifloxysulfuron (2-pyridinesulfonamide, N-[(4, 6-dimethoxy-2-pyrimidinyl) amino] carbonyl]-3-(2, 2, 2-trifluoroethoxy)-, monosodium salt, monohydrate), flazasulfuron (1-(4, 6-dimethoxypyrimidin-2-yl)-3-(3-trifluoromethyl-2-pyridylsulfonyl)urea), foramsulfuron (2-[3-(4,6-Dimethoxy-2-pyrimidinyl)ureidosulfonyl]-4-(formamido)-N,N-dimethylbenzamide), pronamide (3, 5-dichloro-N-(1, 1-dimethyl-2-propynyl) benzamide), simazine (2-chloro-4, 6-bis(ethylamino)-s-triazine), atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine), sulfosulfuron (1-(4,6-dimethoxypyrimidin-2-yl)-3-(2-ethylsulfonylimidazo[1,2-a] pyridine-3-ylsulfonyl)urea), ethofumesate (2-ethoxy-2,3-dihydro-3,3-dimethyl-5-benzofuranyl methanesulfonate), chlorflurenol (Methyl 2-chloro-9-hydroxyfluorene-9-carboxylate), calcium arsenate (Ca$_3$(AsO$_4$)$_2$), endothall (7-Oxabicyclo (2,2,1)heptane-2,3-dicarboxylic sodium), bispyribac sodium (sodium 2,6-bis[(4,6, dimethoxypyrimidin-2-yl)oxy]benzoate), and amicarbazone (4-amino-N-(1, 1-dimethylethyl)-4, 5-dihydro-3-(1-methylethyl)-5-oso-1 H-1, 2, 4-triazole-1-carboxamide). (Toler, 2007). The main concern with the application of post-emergence herbicide is the safety on the non-target species (Baldwin, 1993). A successful application of post-emergence herbicide provides the best control with minimum disturbance to the turfgrass surface and non-target grass health. Coats and Krans (1986)
found that ethofumesate causes late green-up speed of bermudagrass in the spring when
applied over 1.1 kg ha\(^{-1}\). A developing resistance to one product after years of application
is another big concern. As an annual type and R-strategy plant, annual bluegrass develops
resistance to certain chemicals at a relatively high speed. The amino acid synthesis
inhibitor herbicides are the most commonly used for annual bluegrass control and also
the most likely to develop resistance by annual bluegrass according to Tranel and Wright
(2002). A population of annual bluegrass in Mississippi was also found to be resistant to
both simazine and atrazine (Kelly and Coats, 1998). Presently, amicarbazone is the only
post-emergence selective herbicide labelled for annual bluegrass control on creeping
bentgrass greens with a single application not exceeding 0.05 kg ha\(^{-1}\), due to creeping
bentgrass injury (McCullough et al., 2013). Ethofumesate is labelled for use on creeping
bentgrass but restricted to California, Idaho, Nevada, Oregon, and Washington only.
While, bensulide, oxadiazon, dithiopyr, siduron are all pre-emergence herbicide labeled
for use on creeping bentgrass greens.

Plant growth regulators (PGR), such as paclobutrazol ((\(\pm\))-(R\(^*\), R\(^*\))-beta-((4-
chlorophenyl)methyl)-alpha-(1,1,-dimethylethyl)-1H-1,2,4,,-triazole-1-ethanol) and
flurprimidol (\(\alpha\)-(1-methylethyl)-\(\alpha\)-[4-(trifluoromethoxy)phenyl]-5-pyrimidinemethanol),
are also used for annual bluegrass population control and seed head suppression in the
spring after creeping bentgrass starts to grow rapidly (Dickens 1979; Gaussoin and
Branham, 1989; Johnson and Murphy 1995; Johnson and Murphy, 1996). The usage of
PGR could take years to achieve the goal of annual bluegrass control and there is also a
high potential for creeping bentgrass injury when the PGR program is misconducted.
So far, there are still golf courses maintaining annual bluegrass greens (Huff, 1999) and most of the cases are found on golf courses with more than 50 years of history. The difficulty and resultant failure to control this invasive species with existing herbicides results in the dominance of annual bluegrass over creeping bentgrass over time under particularly more intensive maintenance on golf greens (Xu and Mancino, 2001).

Methiozolin as a newly developed selective herbicide

Methiozolin, from the isoxazoline chemical family, is a novel selective herbicide developed by Moghu Research Center, a South Korean private company founded in 2007 (Koo et al., 2013) and registered in March 2010 for turfgrass use in South Korea (Askew and McNulty, 2014). It differs from all the existing herbicide classes and shows effective control on annual bluegrass. It was first developed as an herbicide for weed control in rice fields by Ryu et al. in 2002. Hwang et al. (2005) reported this chemical being efficient on the control of barnyardgrass (*Echinochloa* spp.), sedge grass and many other kinds of broadleaf annual weeds. Koo and Hwang (2008) also found this herbicide being efficient on annual bluegrass and large crabgrass (*Digitaria sanguinalis*) control and safe to both cool-season and warm-season turfgrass species, including creeping bentgrass, perennial ryegrass, tall fescue and bermudagrass.

The mechanism of methiozolin action within plants still remains uncertain. There are two possible theories. Lee et al. (2007) found biosynthesis inhibition of both cellulose and hemicellulose in corn roots after exposure to a very low rate of methiozolin. They also tested methiozolin on barnyardgrass and observed a cessation of the shoot and root growth.
growth in the seedling stage. However, this cessation of growth was not associated with any other known modes of herbicide injury like twisting or changes in color.

The most recent research conducted by Grossmann et al. (2011) found a possibility of methiozolin inhibiting tyrosine aminotransferase (TAT), which is an enzyme related to the biosynthesis of plastoquinone. This inhibition is found in duckweed (Lemna paucicostata L.) and could be a possible explanation of the growth regulation effect of methiozolin. Tresch et al. (2012) also found similar effects of methiozolin on a recombinant tyrosine aminotransferase on Arabidopsis thaliana and other tyrosine aminotransferase isoenzymes on Arabidopsis and other species.

Although, the mechanism of methiozolin in plant metabolism and the site of herbicidal action remains uncertain, there is some research studying the primary absorption spot of this chemical in different plant tissues and the translocation characteristics of methiozolin within the plant. Koo et al. (2013) found that methiozolin can be readily absorbed by both the root and the leaf. However, after taken in by the leaves there is limited phloem transportation to the rest of the plant. After absorption by the roots, methiozolin can be translocated through the whole plant by the xylem. The herbicidal effects of different application technologies also suggests that foliar application achieved less than 10% control even with the highest application rate of methiozolin (2 kg ha⁻¹). Root application alone and root plus foliar application have similar control efficiency, almost 100% control at the rate of 1 kg ha⁻¹. Koo et al. (2013) also suggested that the translocation of methiozolin through cell membrane was more
likely to be an active absorption rather than simple diffusion according to a kinetics study.

In research of methiozolin absorption and translocation in annual bluegrass, Flessner et al. (2013) found similar results as Koo et al. (2013), that there was more methiozolin translocated upward when applied to the foliage and when applied to the roots methiozolin were translocated mainly to the crown (≤ 30 μg methiozolin per g plant tissue) rather than the leaves (< 8 μg methiozolin per g plant tissue). They also found 99.9% (95% confidence interval) annual bluegrass control when applied before emergence and it was not affected by soil type or methiozolin rate. When applied post-emergence, there was no more than 50% of annual bluegrass controlled 25 days after treatment and less than 80% of annual bluegrass controlled 39 days after treatment. In this research, there was significant difference between soil types, methiozolin rates or treatment location (soil, foliage, soil + foliage). The only significant difference was the growth stage of annual bluegrass when treated. The result showed there was 50% control on two-tiller annual bluegrass seedlings and 28% control on six-tiller annual bluegrass seedlings.

A greenhouse experiment conducted by Brosnan et al. (2013) also found 83% annual bluegrass control with soil-plus-foliar methiozolin and ≤11% annual bluegrass control with foliar only methiozolin on a sand-based rootzone and 33-61% annual bluegrass control with soil-plus-foliar methiozolin and ≤ 8% control with foliar only methiozolin on a soil-based rootzone. A field study of methiozolin on annual bluegrass control was also conducted by Brosnan et al. (2013) on golf putting greens and research
facilities in Tennessee and Texas. They found that the annual bluegrass control in the fall was significantly affected by the methiozolin rate, application time and sequential applications. On both sand-based and soil-based putting greens, 1 kg ha\(^{-1}\) methiozolin had more annual bluegrass control than 0.5 kg ha\(^{-1}\) methiozolin treatment. With only a single application of methiozolin, there was more control on annual bluegrass when it was applied in November and December than applied in October. A sequential application of methiozolin, either two applications (October to November, November to December) or three applications (October to December), had greater annual bluegrass control than a single application, especially on a sand-based putting green. With only one application of methiozolin in the fall, there was more annual bluegrass control on soil-based greens than sand-based greens. However, the comparison between the field study on sand-based and soil-based putting greens was merely an estimation and was not supported statistically.

As to spring applications of methiozolin, a field experiment was conducted on a creeping bentgrass putting greens in Georgia. McCullough et al. (2013) found that with two applications of methiozolin at the rate of 0.84 kg ha\(^{-1}\) and 1.68 kg ha\(^{-1}\), annual bluegrass control reached 58% and 93%, respectively, regardless of whether treatment was initiated in February/March or May. However, with a lower methiozolin rate (0.42 kg ha\(^{-1}\)), there was 23% annual bluegrass control at 8 weeks after initial treatments (WAIT) if the treatment was initiated in February/March; and 50% control at 8 WAIT if the initial treatment is in May. A growth chamber experiment also showed a higher methiozolin rate was needed to achieve 50% injury on annual bluegrass under 10 °C than under 20 °C and 30 °C (McCullough et al., 2013).
Methiozolin has been proved to be safe on creeping bentgrass by multiple research. A research study on the tolerance of multiple bentgrass species to methiozolin has been conducted in a greenhouse at the University of California, Riverside and Auburn University (Hoisington et al., 2014). Nine creeping bentgrass cultivars, including Focus, T-1, Penn G-2, Bengal, 007, Tyee, Penn A-4, 96-2, Penncross, and one cultivar of colonial bentgrass (*Agrostis capillaris*, SR 7150) and one cultivar of velvet bentgrass (*Agrostis canina*, SR 7200) received two applications of methiozolin at the rate of 0, 0.6, 1.1, 2.2, 4.5, and 9.0 kg a.i. ha$^{-1}$. The result showed that creeping bentgrass had more tolerance to methiozolin than colonial bentgrass and velvet bentgrass. The methiozolin rates that caused 25% of injury for these three species were 1.1, 0.2, and 0.3 kg a.i. ha$^{-1}$, respectively. For clipping yield reduction, 1.9, 0.4 and 0.4 kg a.i. ha$^{-1}$ methiozolin was needed to achieve a 50% of clipping yield reduction compared to the no methiozolin control in creeping bentgrass, colonial bentgrass and velvet bentgrass, respectively. A field study of spring application of methiozolin at the rate of 0.5 kg a.i. ha$^{-1}$ and 0.75 kg a.i. ha$^{-1}$ for annual bluegrass control on creeping bentgrass golf greens in Virginia had shown neither significant injury nor significant discoloration on creeping bentgrass (Askew and McNulty, 2014). Another field study of the application timing of methiozolin in the spring was performed on creeping bentgrass golf greens at multiple sites in Georgia (McCullough et al. 2013). McCullough et al. (2013) found less than 8% of injury on creeping bentgrass 2 and 4 WAIT when two applications of 1.68 kg a.i. ha$^{-1}$ methiozolin were applied in February and March. However, when the two applications were made in May at the same rate, there was no creeping bentgrass injury observed.

Nitrogen as an essential plant nutrient
Nitrogen is one of the most important and the most common macronutrient supplements in the turfgrass system, followed by phosphorus and potassium. As one of the essential plant nutrients, nitrogen plays an important role in the lateral growth, recuperative potential, and chlorophyll formation of the plant. As a result, nitrogen has a great influence on the recovery rate, color and stress tolerance of the plant (Schlossberg and Schmidt, 2007; Beard, 1973; Turner and Hummel, 1992). The influence of nitrogen on the growth of annual bluegrass is very controversial. As early as the 1930’s, Sprague and Burton (1937) reported a reduction of annual bluegrass seed head production when applied with 34 kg ha\(^{-1}\) of nitrogen compared with no nitrogen application. Dest and Allinson (1981) confirmed this idea with one of their two field studies on golf course fairways. On the other hand, there are other reports saying that nitrogen at a high rate of 148 kg ha\(^{-1}\) will increase the aboveground biomass of annual bluegrass in the loamy sandy soil (Juska and Hanson, 1969). So far the effects of nitrogen on the population of annual bluegrass as a weed in other turfgrass system is still unclear.

Nitrogen, as an enhancement to creeping bentgrass color and lateral growth, plays an important role in turfgrass surface restoration after an efficient chemical control of annual bluegrass. It helps with vegetation recovery from bare spots/voids and restoration of creeping bentgrass color. Increased nitrogen rate has been reported to decrease creeping bentgrass chlorosis after the application of ethephon, a PGR that suppresses annual bluegrass seed head production and growth (McCarty et al., 2005; McCullough et al., 2005). Since methiozolin has some effects on the color and growth of creeping bentgrass similar to PGRs, it is interesting to further study the effects of nitrogen on the surface quality of creeping bentgrass in conjunction with methiozolin applications.
Besides the effects of nitrogen on the growth of both annual bluegrass and creeping bentgrass, it can also influence the efficiency of the herbicides (Morton and Harvey 1994; Nalewaja et al. 1998). Cathcart et al. (2004) found that under low nitrogen conditions, 5.15 g ha\(^{-1}\) nicosulfuron was needed to reduce 50% growth of green foxtail (*Setaria viridis* (L.) *Beauv.*), while only 0.90 g ha\(^{-1}\) of nicosulfuron was needed under high nitrogen conditions. The reason for improved control of certain herbicides is not fully understood yet, but it seems to be related to increased absorption by the target plant and translocation within the plant (Liebl et al. 1992; Nalewaja and Matysiak 1993a, 1993b). A laboratory study conducted by Brosnan et al. (2010) found that extra supplement nitrogen increased the translocation of flazasulfuron between annual bluegrass tissues by 18% at one hour after treatment and by 22% at four hours after treatment compared with the no nitrogen control. Methiozolin as a novel herbicide from isoxazoline family, the effects of nitrogen on the translocation and metabolism of methiozolin within the plant tissue is still unclear.

Instead of nitrogen increasing the control efficiency, it also has the potential to increase annual bluegrass tolerance to herbicides. From both a field study and a laboratory study at the Horticultural Research Farm II in New Jersey, McCullough et al. (2011) found that nitrogen improves tolerance of both annual bluegrass and creeping bentgrass to bispyribac-sodium due to an increased metabolism of this chemical in both species. Inconsistency of nitrogen supplement on the control efficiency of herbicides also has been reported to atrazine (1-Chloro-3-ethylamino-5-isopropylamino-2, 4, 6-triazine), mesotrione (2-[4-(Methylsulfonyl)-2-nitrobenzooyl] cyclohexane-1, 3-dione), nicosulfuron (2-[(4,6-dimethoxypyrimidin-2-yl)carbamoylsulfamoyl]-N,N-dimethylpyridine-3-
Since nitrogen can directly influence the seed production of annual bluegrass, the lateral growth/recuperative potential of creeping bentgrass and have a potential influence on the performance of methiozolin from both an efficiency and safety standpoint, it is an important factor to considerate in an annual bluegrass/creeping bentgrass ecosystem, and may play an essential role in competition and conversion between these two species. A pot study conducted by Nam-il et al. (2001) in Japan suggested that the shoot and roots growth of annual bluegrass increased with nitrogen rate until it reached a peak (at 300 ppm N) then started to decline with higher nitrogen rates. On the other hand, creeping bentgrass responds to nitrogen more slowly and reaches the peak at 1,000 ppm N rate. Asano and Ichikawa (2000) found that annual bluegrass has the strongest response to nitrogen at low nitrogen levels among 12 turf weed species. It was deduced that annual bluegrass is more competitive at a low nitrogen level (Nam-il et al, 2001).

Because of the uncertainty of the role of nitrogen in a methiozolin-applied annual bluegrass/creeping bentgrass ecosystem, it is interesting to study the effects of nitrogen on the efficiency of methiozolin on annual bluegrass control and also the safety of methiozolin on creeping bentgrass. One of the major objectives of this research was to determine the best nitrogen rate that can benefit the recovery and performance of creeping bentgrass without encouraging the infestation of annual bluegrass after the methiozolin treatments.
Chapter 2: Spring Application of Nitrogen and Methiozolin on Annual Bluegrass Control on Golf Greens after Fall Treatment

Introduction

Methiozolin has proven to be a more effective post-emergence herbicide on annual bluegrass control when applied in the fall than in the spring (Koo et al., 2013). A demonstration trial of methiozolin fall application was made on the practice putting green at the Ohio State University Golf Club, Columbus, Ohio. After three applications of methiozolin at the rate of 0.53 kg a.i. ha\(^{-1}\) at two week intervals, about 75\% of the annual bluegrass was killed the next spring (Fang et al., unpublished data). However, there was a tremendous number of voids left on the putting surface due to the effective control of annual bluegrass from the fall methiozolin treatments and a relatively slow recovery rate of creeping bentgrass. The voids created by annual bluegrass control resulted in a rather irregular putting surface that creates unacceptable putting quality. These voids needed to be filled in by adjacent creeping bentgrass encroachment as rapidly as possible in the spring to restore acceptable playability to the putting surface and avoid the potential for annual bluegrass re-encroachment from seed bank germination. Nitrogen fertilization rates, application frequency and spring versus no spring methiozolin were evaluated to determine their influence on the lateral recovery/recuperation rate of the adjacent creeping bentgrass into the voids. The research question is how to encourage the voids to
recover quickly by reestablishment to creeping bentgrass for playability and lessen the opportunity for encroachment by annual bluegrass.

In the spring of 2014 and 2015, nitrogen rates and fertilizing frequencies with and without spring methiozolin treatments were tested on the area where voids were formed after methiozolin fall applications. The objectives of this experiment were 1) to determine the effects of nitrogen rates and frequencies on the surface quality and lateral recovery rate of creeping bentgrass into the voids; 2) to determine the efficiency of spring methiozolin after fall methiozolin treatments on annual bluegrass control and re-encroachment from potential seed bank germination; and 3) to find any interaction between methiozolin, nitrogen rates and fertilizing frequency on creeping bentgrass surface quality, voids recovery and annual bluegrass control.

Material and Methods

A two-year field study was conducted from October, 2013 to July, 2015 on the south side of the Scarlet putting green at the Ohio State University Golf Club, located at Columbus Ohio. The study was established on a green which had been renovated in 2010. The creeping bentgrass cultivar on this green was “L-93”. After approximately 5 years, there was an existing stand of annual bluegrass averaging to 20% coverage throughout the whole green. According to the soil test, the soil pH on this green was 7.2. The available macronutrient in the soil, including phosphorus, potassium, calcium and magnesium, were 224.17 kg ha$^{-1}$, 221.93 kg ha$^{-1}$, 3,511.63 kg ha$^{-1}$ and 210.72 kg ha$^{-1}$, respectively. The available micronutrients in the soil, including iron, manganese, zinc and copper, were 63.89 kg ha$^{-1}$, 6.73 kg ha$^{-1}$, 16.03 kg ha$^{-1}$ and 3.92 kg ha$^{-1}$, respectively.
The area was functioning as a practice putting green and maintained the same as the other golf greens on the Scarlet course. The green was mowed daily at the height of 3.2 mm with a walk-behind reel mower. The area was verticut (ThatchAway Techs) on April 14; and topdressed, verticut (Graden AIRROW verticutter) and core aerified with 12.7 mm hollow tines (Toro PROCORE 648) on April 21. No other culture practices involving soil disturbance were performed during the study. The entire green was topdressed three times during the growing season on June 17, June 26 and July 7. All the fertilizer and PGR applications were skipped on the testing area, since nitrogen is one of the research treatments and methiozolin is considered to have PGR effects.

For disease control, a total of 38.92 kg a.i. ha\(^{-1}\) of Chlorothalonil (tetrachloroisophthalonitrile) (Daconil Action, Syngenta Crop Protection, Greensboro, NC; Manicure Ultra, Lesco Lab, Cleveland, OH), 0.426 kg a.i. ha\(^{-1}\) of pyraclostrobin (carbamic acid, [2-[[1-(4-chlorophenyl)-1H-pyrazol-3-yl]oxy]methyl]phenyl)methoxy-,methyl ester) (Insignia, BASF Corporation, Research Triangle Park, NC) were applied to the area during the experiment period. Modified alkylated polyol (Revolution, Aquatrols Corp of America, Paulsboro, NJ) was also applied as a wetting agent at the rate of 2.14 kg a.i. ha\(^{-1}\) on July 13.

A 2 × 4 × 3 factorial experiment was set up as a split-plot design with three replications. The main plots, 2 levels of methiozolin (0, 0.53 kg a.i. ha\(^{-1}\)), were randomized in each of the three blocks. Each main plot was split into 12 sub-plots. Four levels of nitrogen rates (0, 6.10, 12.20 and 24.40 kg N ha\(^{-1}\)) and three levels of application frequencies (once per month, twice per month and four times per month) were
randomized jointly within the 12 subplots in each main plot. All the treatments are listed in Table 2.1. The size of a subplot was 0.91 by 0.91 m. There was a 0.15 m border space between the subplots and 0.3 m border space between the main plots. The whole experiment area was 19.35 by 4.57 m. In the second year (2015), the whole experiment was repeated with the same design and laid in a new area adjacent to the 2014 study on the same putting green. All the treatments were re-randomized in the repeated experiment.

In the field preparation stage, the whole experiment area was treated with methiozolin (PoaCure, Moghu Research Center, Daejeon, South Korea) at the labeled rate (0.53 kg a.i. ha⁻¹). Three treatments of methiozolin at 2 week intervals were initiated on October 2 in 2013 and September 24 in 2014. The fall methiozolin treatment is as shown in Table 2.2.

The first applications of spring methiozolin treatment and nitrogen treatments were started on April 16 in 2014 and April 28 in 2015. The application dates for the methiozolin and nitrogen treatments and the daily high/low temperature are as listed in Table 2.3. Ammonium sulfate (S’Sul, American Plant Food Corp., Galena Park, TX) was used as the N-source. All treatments were sprayed with a CO₂ backpack sprayer (300 kPa) equipped with a Tjn_TP6503 (Teejet, Wheaton, IL) flat fan nozzle, which was calibrated to deliver 845.88 L liquid per ha.

An initial baseline data was taken before the first treatment application in each year and all the data was collected every two weeks. The measurements focused mainly on two aspects: color/quality of the creeping bentgrass, the percent voids coverage (voids
resulting from annual bluegrass kill from the fall applications in 2013 and 2014) and the annual bluegrass population. The measurement methods for turf color/quality included visual assessment, normalized difference vegetation index (NDVI), dark green color index (DGCI) and digital image analysis (DIA). The measurement methods for percent voids coverage and annual bluegrass population included visual assessment, grid counting and digital image analysis (DIA).

Visual assessment of creeping bentgrass color/quality was rated according to the guide to National Turfgrass Evaluation Program (NTEP) turfgrass ratings procedure. Creeping bentgrass spring green-up color was evaluated based on a 1 to 9 scale, with 1 being entirely straw brown; 6 being minimum acceptance color by a golf course superintendent; and 9 being completely dark green color. The percent voids coverage and annual bluegrass population were rated according to the living ground cover evaluation from the NTEP Turfgrass Ratings Guide. This coverage assessment expresses the damage from the annual bluegrass encroachment and the recovery rate of creeping bentgrass into the voids to an acceptable level of putting surface quality after annual bluegrass was eliminated. The same person took all the visual assessments every two weeks over the two years experimental period.

Normalized difference vegetation index first raised by Rouse et al. (1973) is a function of visible red reflectance (VIS) and near-infrared reflectance (NIR).

\[
NDVI = \frac{(NIR - VIS)}{(NIR + VIS)}
\]
Multiple scientists have utilized NDVI as a method to evaluate turfgrass canopy characteristics, especially turfgrass color (Trenholm et al., 1999; Jiang et al., 2003; Xiong et al., 2007; Sönmez et al., 2008). NDVI was taken with a TCM 500 NDVI turf color meter (FieldScout, Spectrum Technologies, Inc., Aurora, IL). The NDVI turf color meter has a light chamber with an internal light source to negate the interference from external light. The measurement area consist of a 7.6 cm diameter circular opening on the bottom of the light chamber. Therefore, three subsamples were randomly assigned in each plot and the average was utilized as the NDVI value of each plot. NDVI data was taken every two weeks concurrent with the visual assessments.

Green Index was taken with the customized Green Index function of the TCM 500 NDVI turf color meter. The Green Index was first set at the beginning of the experiment in the spring 2014. A 6 score was taken as the minimum color acceptance and the setting was not changed throughout the two year experiment period. The turf color meter offers Green Index readings according to the same standard and gives Green Index readings from 1 to 9. Three subsamples were randomly assigned in each plot and the average was utilized as the Green Index value of each plot. Green Index data was taken every two weeks concurrent with NDVI and visual assessment.

Grid counting was performed to offer an objective presentation of the percent voids coverage and the population of annual bluegrass in addition to the visual assessment. The grid is 0.91 m by 0.91 m and covered the whole sub-plot with a total of 121 intersections at a 76.2 mm by 76.2 mm spacing. Any presence of voids or annual bluegrass living tissue within the range of a 24.26 mm diameter circle at the intersection
was considered a positive count. The total positive counts of either voids or annual 
bluegrass living tissue divided by 121 was taken as the percent coverage of the latter two 
measurements. The grid counting was performed by the same person throughout two-year 
experimental period and was conducted before the initial treatments and every month 
after the initial treatment date in the spring.

Digital image analysis is a new method for turfgrass surface quality evaluation. 
Richardson et al. (2001) has found that digital image analysis has lowered the mean 
variance of percent coverage of bermudagrass from 99.12 using visual assessment and 
13.18 using the grid counting method to 0.65, which means digital image analysis is more 
accurate and objective in determination of turfgrass coverage. A 0.5 m by 0.6 m light 
photo box (Digital analysis light box assembly, NexGen Turf Research, Albany, Oregon) 
and a digital camera (Sony SLT-A57, SAL1855 lens, Sony Corp.) was utilized to take 
one photo from each sub-plot every two weeks. One portable power source (Powerpack 
600, Duracell, Bethel, CT) was attached to the light box to power four compact 
fluorescent bulbs with 63662 cd as a constant light source in the box. The camera was set 
at manual model and a 3568 × 2368 digital image was taken with 0.62 second exposure 
time and 100 ISO Sensitivity. Photos were saved into Joint Photographic Experts Group 
(JPG) format, loaded into a personal computer and analyzed with ImageJ (ImageJ, U. S. 
National Institutes of Health, Bethesda, MD). The red, green and blue (RGB) levels will 
be exported and converted into Hue, Saturation and Brightness (HSB) parameters. The 
HSB values would be used in the Dark Green Color Index (DGCI) for turfgrass color 
analysis. Coverage readings are going to be counted as green color pixel numbers by 
imageJ.
Analysis of all the data was performed with SAS 9.3 (SAS Institute Inc., Cary, NC) and Microsoft Excel (Microsoft Office Professional Plus 2013). ODS Graphics was used for the test of the assumptions of ANOVA and PROC GLM was utilized in SAS for ANOVA test. Fisher’s protected least significant difference (LSD) values for mean comparisons ($p \leq 0.05$). Significant interactions were detected between years and the treatments; thus, data from each year were analyzed and discussed separately.

Results

_Creeping Bentgrass Color/Quality_

Creeping bentgrass color/quality has been evaluated by visual scoring, NDVI, Green Index and digital image analysis methods to determine the effects of spring methiozolin, nitrogen rates and fertilizing frequency on the surface color/quality of creeping bentgrass. There were similarities among different methods of creeping bentgrass color/quality measurements. Most of the data showed no interaction of methiozolin*nitrogen rates, methiozolin*fertilizing frequency and methiozolin*nitrogen rates*fertilizing frequency. On multiple dates after the initial treatment (April 16, 2014), there were significant differences ($p \leq 0.05$) between spring methiozolin treatments and no spring methiozolin treatments, and significant interactions ($p \leq 0.05$) between nitrogen rates and fertilizing frequencies in 2014. No significant differences occurred between spring methiozolin treated and untreated plots in 2015.

Table 2.4 shows the NDVI results for creeping bentgrass as influenced by methiozolin, nitrogen rates and fertilizing frequency in 2014. According to the ANOVA results, there was no significant difference in NDVI among the plots before the
treatments. Two weeks after the first methiozolin application, there was a significant difference ($p < .0001$) observed between methiozolin treated and untreated plots. Methiozolin treated plots had a higher NDVI, meaning a darker green color than methiozolin untreated plots. Four weeks after the first methiozolin application on April 30 (two weeks after the second application), methiozolin treated plots had significantly ($p < .0001$) lower NDVI readings than methiozolin untreated plots. The difference lasted from May 13 (four weeks after the initial application, two weeks after the 2nd application, $p < .0001$), May 28th (six weeks after the initial application, and two weeks after the 3rd application, $p < .0001$), to June 12 (eight weeks after the initial application, and two weeks after the 4th application, $p = 0.0008$) and until June 25 (ten weeks after the initial application, four weeks after the 4th application, $p = 0.0402$). Twelve WAIT of methiozolin, there were no differences on creeping bentgrass NDVI between methiozolin treated and untreated plots. This means in 2014, spring applications of methiozolin at the rate of 0.53 kg a.i. ha$^{-1}$ with four applications at two-week intervals had significant negative effects on the color/quality of creeping bentgrass during the application from two WAIT to ten WAIT.

However, this negative effect of methiozolin on the spring color of creeping bentgrass was not observed in 2015. According to Table 2.5, the NDVI of the methiozolin treated plots and methiozolin untreated plots showed no significant differences. This is also as shown in Figure 2.1. The NDVI was significant different on four dates in 2014 and no significant difference was observed in 2015.
In the Table 2.4, there was a significant difference between nitrogen rates (p < 0.0001) and fertilizing frequencies (p ≤ 0.05) during the application period. There were also significant interactions (p ≤ 0.05) between nitrogen rates and fertilizing frequencies. In Table 2.5, there was one date (June 23, 2015) resulting in significant interactions. As a result, the interactions between nitrogen rates and fertilizing frequencies will be discussed below for both 2014 and 2015.

Figure 2.2 shows the significant interactions (p = 0.0181) between nitrogen rates and fertilizing frequencies two years. There was only one application for plots fertilized at the frequencies of once per month and twice per month two years. Similarity for the latter two frequencies as shown in Figure 2.2 (a) and Figure 2.2 (b), the NDVI of creeping bentgrass increases with higher nitrogen rates in both 2014 and 2015. In Figure 2.2 (c), the NDVI of creeping bentgrass after two applications of nitrogen fertilizer at one week intervals, in 2014 resulted in the 12.2 kg N ha\(^{-1}\) having the highest NDVI. This means that 12.2 kg N ha\(^{-1}\) applied every week provided better creeping bentgrass spring color than 24.4 kg N ha\(^{-1}\) applied every two weeks. In 2015, the best nitrogen rate was the highest rate, 24.4 kg ha\(^{-1}\) applied every week.

Similar patterns can be seen in Figure 2.3 at four years. When applied at four weeks interval [Figure 2.3 (a)] and two weeks intervals [Figure 2.3 (b)], the NDVI of creeping bentgrass increased with higher nitrogen rates, and when applied every week [Figure 2.3 (c)] 12.2 kg N ha\(^{-1}\) resulted in the highest NDVI of creeping bentgrass in 2014. In 2015, the NDVI of creeping bentgrass increased with nitrogen rates when applied once a month [Figure 2.3 (a)]. When applied at two weeks interval [Figure 2.3...
(b)], the 12.2 kg N ha\(^{-1}\) resulted in the highest NDVI of creeping bentgrass. When applied every week [Figure 2.3 (c)] both the 12.2 kg ha\(^{-1}\) and 24.4 kg N ha\(^{-1}\) resulted in a lower NDVI than the 6.1 kg N ha\(^{-1}\) in 2015. The same NDVI pattern continued until twelve WAIT (Figure 2.7), which is also six weeks after the last nitrogen application. At this time, there was no significant interactions between nitrogen rates and fertilizing frequencies according to Table 2.4 and Table 2.5, but still significant differences between nitrogen rates in 2014 and fertilizing frequencies in 2015.

In conclusion, NDVI of creeping bentgrass was mainly affected by nitrogen rate. In 2014, 24.4 kg N ha\(^{-1}\) applied once a month or twice a month and 12.2 kg N ha\(^{-1}\) applied every week resulted in a higher NDVI which also means darker green color of creeping bentgrass. Also, in 2014, spring methiozolin treatments had a significantly more negative effects on the color of creeping bentgrass than in 2015. In 2015, NDVI of creeping bentgrass was generally higher than 2014 and less affected by spring methiozolin. Also, in 2015 less nitrogen applications were needed to achieve high creeping bentgrass color. The highest NDVI of creeping bentgrass occurred with 12.2 kg N ha\(^{-1}\) twice per month or 6.1 kg N ha\(^{-1}\) four times per month. This is probably caused by a warmer temperatures in April and May of 2015 than 2014 (air temperature data, Table 2.3).

Green Index of creeping bentgrass as influenced by methiozolin, nitrogen rates and fertilizing frequency in 2014 (Table 2.6) shows similar ANOVA results as the NDVI of creeping bentgrass in Table 2.4. Spring methiozolin had significant (p ≤ 0.05) negative effects on the Green Index of creeping bentgrass. The Green Index started to decline at two WAIT and lasted to four weeks after the last treatment in 2014 (Figure 2.8). Both
nitrogen rates and fertilizing frequencies have significant ($p \leq 0.05$) effects on the Green Index of creeping bentgrass. There was also significant ($p \leq 0.05$) interactions between nitrogen rates and fertilizing frequencies. In 2015, the Green Index (Table 2.7) was significantly lower on one date for the spring methiozolin treated plots compared to the untreated plots ($p =0.0119$). There was also one date that the methiozolin treated plots had a significantly higher Green Index value than untreated plots ($p =0.0419$). According to Table 2.7, there are limited interaction between nitrogen rates and fertilizing frequencies. Most of the differences on the Green Index of creeping bentgrass comes from the effects of nitrogen rates, which is similar to the NDVI results in Table 2.5.

Figure 2.9 shows similar results to Figure 2.2. The only difference is that NDVI of creeping bentgrass is the highest when applied at the rate of 12.2 kg N ha$^{-1}$ every week in 2014 (Figure 2.2). Figure 2.8 shows that higher nitrogen rates result in higher Green Index values of creeping bentgrass at all application frequencies starting two weeks after the initial treatment in both 2014 and 2015. Figure 2.10 to Figure 2.14 are the Green Index of creeping bentgrass from four, six, eight, ten and twelve weeks after the initial application in 2014 and 2015. There is good similarity between these figures and the figures for the NDVI of creeping bentgrass. The same pattern and conclusion have been drawn from Figure 2.10 to Figure 2.14 as those from the NDVI. The NDVI in 2014 resulted in the 24.4 kg N ha$^{-1}$ applied once a month or twice a month and the 12.2 kg N ha$^{-1}$ applied every week producing a darker green color of creeping bentgrass. In 2015, 12.2 kg N ha$^{-1}$ twice per month and 6.1 kg N ha$^{-1}$ four times per month were the best nitrogen application strategies optimum spring color of creeping bentgrass.
The visual assessment of creeping bentgrass color influenced by methiozolin, nitrogen rates and fertilizing frequency in 2014 and 2015 is reported in Figures 2.9 and 2.10. A 1 to 9 scoring system was used based on the rules of the National Turfgrass Evaluation Program. The visual evaluation was conducted by one person over the two year period. From these two tables, creeping bentgrass has a darker green color in the spring of 2015 than in the spring of 2014. This observation is consistent with the NDVI data and Green Index data taken with the NDVI turf color meter.

There was no significant difference between spring methiozolin treated and untreated plots on most of the dates in 2014, except for May 13 (Table 2). This was also shown in Figure 2.15, where the only significant difference between methiozolin treated and untreated plots is four WAIT in 2014. There was no significant difference on the visual assessment of creeping bentgrass color caused by methiozolin in 2015 (Table 2.9 and Figure 2.15). There was however a significant difference among nitrogen rates (p < .0001) from the second week after the initial application (Tables 2.8 and 2.9) until the end of the experiment (p < .0001) in both 2014 and 2015. There was also a significant difference among fertilizing frequencies (p < .0001) throughout the entire experimental period except for two WAIT in 2014. In 2015, there was no significant difference between fertilizing frequencies until four WAIT and lasted for another four weeks. Since there are significant interactions between nitrogen rate and fertilizing frequency both in 2014 and 2015, the effects of nitrogen rates on the visual score of creeping bentgrass color at each application frequency will be discussed.
The color of creeping bentgrass two WAIT is presented in Figure 2.16. At this time, only one application has been applied to plots receiving nitrogen once per month and twice per month. Two applications have been applied to plots with a fertilizing frequency of four times per month. There should have be no difference between (a) and (b) (Table 2.15). The visual score of creeping bentgrass color in 2014 has the same pattern in Figure 2.16 (a) and (b) with 24.4 kg N ha\(^{-1}\) having a much higher creeping bentgrass color score than the 12.2 kg N ha\(^{-1}\) treatments. Figure 2.16 (c) shows that in 2014, the 12.2 kg N ha\(^{-1}\) and 24.4 kg N ha\(^{-1}\) treatments have similar green color, which is much higher than the control group and 6.1 kg N ha\(^{-1}\) plots. In 2015, there are no significant interactions between nitrogen rates and fertilizing frequencies at two WAIT. The color of creeping bentgrass is only influenced by nitrogen rates, with an increase in creeping bentgrass color with increasing nitrogen rate from 0 kg ha\(^{-1}\), to 6.1 kg ha\(^{-1}\), to 12.2 kg ha\(^{-1}\), to 24.4 kg ha\(^{-1}\). (Table 2.9). In 2015 (Table 2.16) shows some difference among fertilizing frequencies, however there was still no significant interaction among nitrogen rates and fertilizing frequencies. Thus, the creeping color score four WAIT in 2015 was still only affected by nitrogen rates, with higher nitrogen rates resulting in a darker green color of creeping bentgrass. Each nitrogen rate was significantly different from other rates according to Table 2.9. Also, the 24.4 kg N ha\(^{-1}\) applied every week had the highest color score at this point. The visual score of creeping bentgrass affected by nitrogen rates four WAIT in 2014 was significantly influenced by fertilizing frequency as shown in Figure 2.17 (a), (b) and (c). Four WAIT, only one application had been made with the once per month frequency, so the pattern in Figure 2.17 (a) is similar to the patterns in Figure 2.16 (a) and Figure 2.16 (b). Figure 2.17 (b) shows the color score
affected by nitrogen rates applied twice per month. The color score still increases with a higher nitrogen rate, but there was less of a difference between the 12.2 kg N ha\(^{-1}\) treatments and the 24.4 kg N ha\(^{-1}\) treatments after two applications. When applied every week, there was less of a difference in color among nitrogen rates after four applications. Also, the plots treated with 24.4 kg N ha\(^{-1}\) had lower color scores than the plots treated with 12.2 kg N ha\(^{-1}\) four WAIT. All nitrogen treatments had significantly higher color scores than untreated plots receiving no nitrogen.

Visual assessment of creeping bentgrass color/quality in 2015 still showed no significant interaction between the nitrogen rates and fertilizing frequencies. The color/quality scores of creeping bentgrass increased with higher nitrogen rates. The color/quality scores from 2014 shows similar results to 2015 (Figure 2.17). When applied once a month, the 24.4 kg N ha\(^{-1}\) plots had significantly higher color/quality scores with scores of 8.0 compared to other nitrogen rates with scores below 6.5. When applied twice a month, there was less difference among nitrogen rates, but the color scores of creeping bentgrass still increased significantly with higher nitrogen rates. When applied every week, the 24.4 kg N ha\(^{-1}\) treatment had the same color scores as the 12.2 kg N ha\(^{-1}\) treatment four WAIT, which is also after four applications of each rate.

Figure 2.19 provides color/quality scores at eight WAIT and one week after the last fertilizer application on the one week interval treatments. At eight WAIT, two applications had been made with the once per month frequency, four applications with the twice per month frequency and eight applications with four times per month frequency. In 2014, there was a significant interaction between nitrogen rates and
fertilizing frequencies. In Figure 2.19 (a), when applied once per month, the 24.4 kg N ha\(^{-1}\) still had the highest color/quality score on creeping bentgrass rated at 8.0, with the 12.2 kg N ha\(^{-1}\) providing a score below 7.0. In Figure 2.19 (b) and (c) when applied twice per month and four times per month, all the nitrogen treatments have a significantly higher color score than untreated control. The color/quality scores of creeping bentgrass increased with increasing nitrogen rate and application frequency.

The color/quality scores from 2015 started to show significant interactions between nitrogen rates and fertilizing frequencies. In Figure 2.19 (a) and (b), when applied once per month or twice per month, the 12.2 kg N ha\(^{-1}\) treatment had the highest color scores. There is some decrease of color/quality at the 24.4 kg N ha\(^{-1}\) every month. When applied every two weeks, the visual color/quality scores of the 24.4 kg N ha\(^{-1}\) plots was even lower than the 6.1 kg N ha\(^{-1}\) treatment. In Figure 2.19 (c), the 12.2 kg ha and 6.1 kg N ha\(^{-1}\) treatments had the highest color/quality score. The 24.4 kg N ha\(^{-1}\) treatment had a color/quality score even lower than the unfertilized check. Since it is eight WAIT and end of June, the high temperature and low humidity caused some burning on the high nitrogen rate plots. This most likely was caused the decrease of creeping bentgrass color/quality with the 24.4 kg N ha\(^{-1}\) treatment at the end of June.

Figure 2.20 shows the visual assessment scores for creeping bentgrass color/quality ten WAIT. All the nitrogen applications were completed by this time. The data from 2014 shows the same pattern as the data from Figure 2.19. The visual assessment scores remained constant from 8 to 10 WAIT (Figure 2.19), except that there was a small decrease in color/quality scores with the once per month treatments having
received a total of only two applications. In 2015, creeping bentgrass color/quality showed less of a negative effect at the 24.4 kg N ha\(^{-1}\) applied once per month. When applied once per month and twice per month, all the nitrogen treatments had color/quality scores significantly higher than the unfertilized treatment but not significantly different between nitrogen rates [Figure 2.20 (a) and (b)]. In Figure 2.20 (c), the 6.1 kg N ha\(^{-1}\) treatment applied every week had the highest color/quality score, but not significantly different from the 12.2 kg N ha\(^{-1}\) treatment. In 2015, the color/quality score of the 24.4 kg N ha\(^{-1}\) treatment was still lower than the untreated treatment which again was most likely due to foliar burn with the high temperatures in June.

In Figure 2.21, there is less difference among nitrogen treatments at twelve WAIT, and the untreated plots gained more color during the natural green-up process. However, there was still significant differences between nitrogen rates (p < .0001, 2014 and 2015), the fertilizing frequencies (p = 0.0236, 2014 and p = 0.0254, 2015) and also significant interactions between these two factors (p = 0.0379, 2014 and p < .0001, 2015) (Table 2.8 and Table 2.9). In 2014, 24.4 kg N ha\(^{-1}\) treatment when applied once per month had much higher color/quality scores than other nitrogen rates and the untreated plots [Figure 2.21 (a)]. In Figure 2.21 (b), when applied twice per month, the color/quality scores of creeping bentgrass increased significantly with increasing nitrogen rate. In Figure 2.21 (c), when applied every week, the 12.2 kg N ha\(^{-1}\) had similar color/quality scores to the 24.4 kg N ha\(^{-1}\).

In 2015, there was less of a difference between nitrogen rates at each frequency and the 6.1 kg N ha\(^{-1}\) treatment applied every week has slightly better color/quality than
the higher nitrogen rate treatments. This is probably because the experiment started one week later in 2015 to avoid the negative effects from cold temperature on potential phytotoxicity of methiozolin on creeping bentgrass. Also, warmer temperatures from the end of April into May in 2015 encouraged more rapid spring green-up of creeping bentgrass leading to less need for nitrogen.

Coverage of Voids

Coverage of voids has been evaluated by visual assessment and grid counting mainly to evaluate the effects of nitrogen rates and fertilizing frequency on creeping bentgrass recovery rate. Visual assessment of the percent coverage of voids was done before the spring methiozolin and nitrogen treatments, and every two weeks after the initial application. Grid counting was conducted before the initial treatments and every month thereafter using a grid with a total of 121 intersections. Since the voids were caused by annual bluegrass that declined after fall applications of methiozolin, and the percent coverage of the voids had variance among plots, so the data was transformed by subtracting the initial percentage of voids from the percent voids coverage on each rating date as the equation shown below.

$$\Delta PVC_a = PVC_a - PVC_0$$

$$\Delta PVC_a = \text{Change of percent voids coverage on date } a$$
$$PVC_a = \text{percent voids coverage reading on data } a$$
$$PVC_0 = \text{initial percent voids coverage before any treatment}$$

The transformed data stands for the change of percent coverage of voids. If it is a positive number, it means there is an increase of percent coverage of voids from the day
before the first application to the rating date. Otherwise, a negative number means there is a decrease of percent coverage of voids from the day before the first application to the rating date. There are six dates of visual assessment of the change of percent coverage of voids in each year, which means the percent coverage of voids was measured visually six times after the first application in each year. Similarly, the grid counting was conducted monthly with three rating dates after the first application of spring methiozolin and nitrogen.

Table 2.10 shows the effects of methiozolin, nitrogen rates and fertilizing frequency on the visual assessment of percent voids coverage in 2014. The column under the date of April 17 2014 shows the initial percent voids coverage before treatments and all the rest of the columns are showing the transformed date. There was no significant difference ($p \leq 0.05$) between methiozolin treated plots and untreated plots from May 1 to the end of the experiment (ANOVA, Table 2.10). Even though at a non-significant level, Methiozolin untreated plots have a greater negative percentage of voids than the methiozolin treated plots. This means there is trend for a decrease of percent voids coverage or bentgrass recovery rate with methiozolin treatments. This may also mean that spring methiozolin treatments slow down the recovery rate of creeping bentgrass into the voids caused by declined annual bluegrass.

According to Table 2.10, nitrogen rate had a significant effect on the change of percent voids coverage at four WAIT (May 13) ($p = 0.0023$), and ten WAIT, (June 25) ($p = 0.0295$). There was no significant difference between the fertilizing frequencies and no significant methiozolin by nitrogen rate, methiozolin by fertilizing frequency, or nitrogen
rate by fertilizing frequency interactions on any dates during the experiment in 2014. However, there was a significant three-way interaction among methiozolin, nitrogen rate and fertilizing frequency on May 1, two WAIT (p = 0.0391) and on May 13, four WAIT (p = 0.0076).

In 2015, there was no significant effects of spring methiozolin, nitrogen rates or fertilizing frequencies on the visual assessment of the changes of percent voids coverage (Table 2.11). In 2015, there was also no significant interaction between methiozolin and nitrogen rates, methiozolin and fertilizing frequency and no three-way interaction between these factors either in 2015. The only significant interaction that occurred in 2015 was between nitrogen rates and fertilizing frequencies on May 12, two WAIT (p = 0.0420), June 19, six WAIT (p = 0.0338) and June 23, eight WAIT (p = 0.0312), according to the ANOVA results in Table 2.11.

Figure 2.22 shows the changes of visual assessment percent voids coverage on spring methiozolin treated and untreated plots in both 2014 and 2015. There was no difference between methiozolin treated and untreated plots on the recovery rate of creeping bentgrass into voids in 2015. Most of the decrease in voids coverage occurred in the time period between two and four WAIT. Unlike 2015, there were some differences between spring methiozolin treated and untreated plots yet not statistically significant according to the ANOVA results in 2014. Plots without spring applications of methiozolin had a greater decrease on the percent coverage of voids and this decrease exists through the whole experiment at a uniform declining rate. The decrease of visual percent coverage of voids with methiozolin, on the other hand, remained similar from
two WAIT to 8 WAIT. The percentage of voids decreased further after 8 WAIT, which was also two weeks after the last application of methiozolin. The decrease of percent voids coverage on methiozolin treated plots was less than plots with no spring methiozolin at the end of the experiment in 2014. The data from 2014 showed some negative effects from spring methiozolin applications on the recovery of creeping bentgrass from voids left by dead annual bluegrass. This negative effect on the recovery rate of creeping into the voids in 2014 was not observed in 2015.

Statistically, there was a significant interaction between methiozolin, nitrogen rates and fertilizing frequencies on the change of percent voids coverage two weeks (p = 0.0391, Table 2.10) and four weeks (p = 0.0076, Table 2.10) after the initial treatment in 2014. There was no significant interaction between methiozolin, nitrogen rates and fertilizing frequencies on any date in 2015. However, there was a significant interaction between nitrogen rates and fertilizing frequencies two weeks (p = 0.0420, Table 2.11), six weeks (p = 0.0338, Table 2.11) and eight weeks (p = 0.0312, Table 2.11) after the initial treatment in 2015. As a result, figures showing the changes of visual assessment percent voids coverage affected by nitrogen rates applied at each frequency are presented for both 2014 and 2015.

Figure 2.23 shows the effects of nitrogen rates on the change of visual assessment percent voids coverage at each application frequencies two WAIT in both 2014 and 2015. There was a noticeable difference of the decrease of percent voids coverage between 2014 than 2015. Treatments with a fertilizing frequency of once a month (a) and twice a month (b) had received only one application of nitrogen. Treatments with a weekly
fertilizing program (c) had received two applications of nitrogen at each rate. In Figure 2.23 (a), 6.1 kg N ha$^{-1}$ had the least decrease of percent voids coverage in both 2014 and 2015. In Figure 2.23 (b), the nitrogen rate resulting with the least recovery was the 12.2 kg ha nitrogen rate. There is no logical explanation for the difference between (a) and (b), since both treatments received only one application at both nitrogen rates. The most possible explanation is that two WAIT was still too early for all the nitrogen rates to have had any significant effects on the recovery of creeping bentgrass. This could also explain the reason why there was a smaller decrease of percent voids coverage with higher nitrogen rates after two applications in 2014 in Figure 2.23 (c).

Figure 2.24 shows the changes of visual assessment percent voids coverage at four WAIT. At this time, there was one application with treatments fertilized once per month (a), two applications on treatments fertilized twice per month (b), and four applications on treatments fertilized four times per month (c). In 2014, more positive effects of each nitrogen rate except Figure 2.24 (a), which has a similar decrease on the percent voids coverage on every nitrogen rate and remains the same shape as Figure 2.23 (a). This is because the plots presented in Figure 2.24 (a) still had received only one nitrogen application. In 2014, treatments fertilized every week and every other week had a greater decrease of percent voids coverage with increased nitrogen rates. The 6.1 kg ha$^{-1}$, 12.2 kg ha$^{-1}$, and 24.4 kg N ha$^{-1}$ all resulted in a greater decrease of percent voids coverage when applied every other week than every week at 4 WAIT. In 2015, (Figure 2.24) the effects of nitrogen rate on creeping bentgrass recovery was different compared to 2014. There was a 5%-10% decrease of voids coverage from two to four WAIT. With only one application of nitrogen applied, the 0 kg N ha$^{-1}$ control had a greater decrease of
percent voids coverage than any of the other nitrogen treatments. The 12.2 kg N ha\(^{-1}\) had the least decrease of percent voids coverage over the four WAIT [Figure 2.24 (a)]. When fertilized twice per month, both the 12.2 kg ha\(^{-1}\) and the 24.4 kg N ha\(^{-1}\) had the least decrease of percent voids coverage [Figure 2.24 (b)]. When fertilized every week (four times per month), these two higher nitrogen rates resulted a greater decrease of percent voids coverage than the no nitrogen control and 6.1 kg N ha\(^{-1}\) in both 2014 and 2015. This is potentially due to the warm temperatures in late April of 2015 compared to 2014. The higher nitrogen rates are more likely to cause chemical stress unless it is fertilized at a high frequency so the nutrients can potentially promote enhanced bentgrass growth and recovery.

Figure 2.25 shows the changes of visual assessment percent voids coverage six WAIT. Two applications of nitrogen were completed for treatments fertilized on a monthly base (a). Three applications were completed for treatments fertilized twice a month (b). Five applications were completed for treatments fertilized every week (c). For 2014, the graphics have some similarity to the nitrogen rate and frequency responses in Figure 2.24. Compared to Figure 2.24, there were more nitrogen treatments that have more than 25% of total voids coverage recovery to creeping bentgrass, including the 12.2 kg N ha\(^{-1}\) treatment applied every month; the 6.1 kg ha\(^{-1}\), 12.2 kg ha\(^{-1}\) and 24.4 kg N ha\(^{-1}\) applied every other week; and the 12.2 kg ha\(^{-1}\) and 24.4 kg N ha\(^{-1}\) applied every week in 2014. In 2015, there was no further decrease of percent voids coverage for any nitrogen treatment, except for the 24.4 kg N ha\(^{-1}\) every week. This is considered to be mainly because that most of the lateral growth/recovery of creeping bentgrass into the voids
occurred within the first couple of weeks in 2015 due to the warm weather and active lateral growth/recovery of creeping bentgrass compared to 2014.

The effects of nitrogen rates on the changes of visual assessment percent voids coverage remains the same at each fertilizing frequency later during the experimental period for both years (Figure 2.26 to Figure 2.28). The conclusion could be made from the changes of visual assessment percent voids coverage over time is that the recovery of creeping bentgrass into adjacent voids is greatly influenced by nitrogen rate. The difference in creeping bentgrass lateral recovery into adjacent voids is more obvious with higher application frequency However, higher nitrogen rates increases the potential for turf burn and chemical stress which starts to have a negative effect on creeping bentgrass color/quality and recovery. In a warm spring like 2015, a lower nitrogen rate and frequency may be a better agronomic strategy and just as effective to increase voids coverage and creeping bentgrass lateral growth and recovery.

Another measurement which was used for the evaluation of voids coverage was by grid counting. A 0.91 by 0.91 m grid was used to cover the entire sub-plot. The grid consisted of 121 intersections for making void counts. Any absence of living green tissue within a 24.26 mm diameter distance of the grid intersections was taken as a positive count. The number of the counts in each plots divided by 121 was the percent voids coverage. To minimize the variance of the initial percent voids coverage among the plots before the treatments were initiated, the data on each rating date was transformed by subtracting the original percent voids coverage from the percent voids coverage on that rating day just as the visual assessment data. The ANOVA results are shown in Table
2.12 and Table 2.13. Since the grid counting was performed every month, there is only three rating dates in each experimental year, namely four, eight, and twelve WAIT. The second column in parenthesis shows the initial percent voids coverage before any treatment.

From Table 2.12, the ANOVA results show that there was no significant differences between methiozolin and non-methiozolin treatments on any rating date in 2014 and 2015. These results are the same as the visual assessment of percent voids coverage results (Table 2.10 and Table 2.11). There was also a significant difference among nitrogen rates on all the rating dates (p = 0.0169, May 13; p = 0.0002, June 12; p = 0.0076, July 9) and significant effects from fertilizing frequency eight WAIT (p = 0.0384) in 2014 (Table 2.12). There was also a three-way interaction between all the factors eight (p = 0.0136) and twelve (p < .0001) WAIT (Table 2.12). However, no significant differences were observed between nitrogen rates or fertilizing frequencies in 2015, nor was there any significant interactions between any factors (Table 2.13).

To compare with results from the change of visual assessment percent voids coverage, the results from grid counting are presented in the same graphic form. Figure 2.29 shows the effects on methiozolin on the changes of grid counting percent voids coverage four, eight, and twelve WAIT. Similar to the ANOVA results from Table 2.12, methiozolin treatments had less decrease of percent voids coverage than non-methiozolin treatments in 2014 until the last rating date of the experiment. In 2015, there was no significant difference between methiozolin treated and non-methiozolin plots. The difference between the grid counting and the visual assessment of percent voids coverage
is that the change of percent voids coverage is more similar in 2014 and 2015 according to the grid counting method. However, in Figure 2.22 there is much more of a decrease of percent voids coverage in 2014 than 2015 according to the visual assessment method.

Figure 2.30 shows the effects of nitrogen rates at each fertilizing frequency on the changes of grid counting of percent voids coverage four WAIT. Compared with Figure 2.24, the visual assessment ratings also taken four WAIT in 2015 are similar to the result from visual assessment, but there was less of a decrease of percent voids coverage in 2014 (Figure 2.30). After application of each nitrogen rate, the 6.1 kg N ha\(^{-1}\) had the greatest decrease of percent voids coverage in both years [Figure 2.30 (a)]. When fertilized twice per month, the 6.1 kg N ha\(^{-1}\) still has the greatest decrease of voids in 2015. Both the 6.1 kg ha\(^{-1}\) and 24.4 kg N ha\(^{-1}\) had less of a decrease of percent voids coverage than the untreated nitrogen control in 2014 [Figure 2.30 (b)]. In Figure 2.30 (c), the grid counting of percent voids coverage from 2015 was similar to the visual assessment, however the grid counting from 2014 showed much less of a decrease of percent voids coverage at the 24.4 kg N ha\(^{-1}\). The treatment with the greatest decrease of percent voids coverage was still the 6.1 kg N ha\(^{-1}\) according to grid counting. Over all, there is less decrease of percent voids coverage with 24.4 kg N ha\(^{-1}\) than the untreated nitrogen control four WAIT in 2014 at all fertilizing frequencies (Figure 2.30).

In Figure 2.31, the grid counting data from 2015 is very similar to the visual assessment of the percent voids coverage eight WAIT (Figure 2.26). When applied once per month, the 24.4 kg N ha\(^{-1}\) had the least decrease of percent voids coverage; when applied twice per month, the 6.1 kg N ha\(^{-1}\) had the most decrease of percent voids
coverage; and when applied every week there was greater decrease of percent voids coverage with the higher nitrogen rates. The grid counting data from 2014, however, showed greater differences in percent voids coverage than the visual assessment data. Instead of promoting a decrease of percent voids coverage (Figure 2.26), there was much less decrease of percent voids coverage with higher nitrogen rates. The only nitrogen strategy that had more decrease of percent voids was the 6.1 kg N ha\(^{-1}\) applied once per month. All the other nitrogen treatments had less decrease of percent voids coverage than the untreated control regardless of the fertilizing frequency. This was probably because of the chemical stress caused by high nitrogen rates, especially the 24.4 kg N ha\(^{-1}\). The grid counting method cannot tell the difference between the voids caused by declined annual bluegrass and voids caused by chemical/fertilizer stress and thinning. This is one possible explanation of the slow recovery of creeping bentgrass into voids with the 24.4 kg N ha\(^{-1}\) in 2014.

Figure 2.32 shows the changes of grid counting percent voids coverage at the end of the experimental period (12 WAIT). In 2015, the grid counting percent voids remained almost the same as at eight WAIT, which means most of the recovery into voids occurred at the beginning of the experiment in 2015. This matches the results from visual assessments. In 2014, there was more decrease of percent voids coverage from eight WAIT to twelve WAIT. The nitrogen strategy with the most decrease of percent voids coverage is still 6.1 kg N ha\(^{-1}\) applied once per month in 2014. The next treatment with the lowest percent voids coverage was 6.1 kg N ha\(^{-1}\) applied every week. There was some decrease of voids with the 24.4 kg N ha\(^{-1}\) after eight WAIT, but this high rate of nitrogen
still causes less decrease on the percent voids coverage than the control group over all three fertilizing frequencies.

In conclusion, the coverage of voids cannot be determined by only the visual assessment or the grid counting. Both methods have their limitations in measuring the changes of percent voids coverage over time. Visual assessment is more efficient in showing the relative differences between treatments, but not representative to the absolute value. The grid counting is more representative to the absolute value, however, there is limitation of its coverage as sometimes it cannot distinguish between the voids caused by chemical/fertilizer injury/thinning and by dead annual bluegrass. As a result, the conclusion is based on the results from both the visual assessment data and grid counting data of percent voids coverage. Spring methiozolin has a negative but not statistically significant effect on the recovery of creeping bentgrass from voids caused by dead annual bluegrass in normal years like 2014. This negative effect is not repeatable in a warmer spring like 2015. Nitrogen rate is another main factor affecting recovery of creeping bentgrass into voids. Under cool weather condition without a significant potential for chemical/fertilizer burn, higher nitrogen rates can better promote the recovery of creeping bentgrass into voids. The nitrogen strategy with the most efficient recovery of creeping bentgrass into voids are 12.2 kg N ha⁻¹ and 24.4 kg N ha⁻¹ every week or 24.4 kg N ha⁻¹ every other week. Under a high temperature and high burn potential conditions, lower nitrogen rates are better for creeping bentgrass recovery by reducing the potential for chemical/fertilizer stress and avoiding a slowdown in lateral growth into voids. In this case, the 6.1 kg N ha⁻¹ applied every week or 12.2 kg N ha⁻¹ applied every other week are a more efficient and safer nitrogen programming strategies.
for a good creeping bentgrass recovery in the spring following a successful annual bluegrass control by methiozolin fall treatments in the previous year.

Annual Bluegrass Population

Annual bluegrass population has been evaluated by visual assessment and grid counting with the same method as the percent voids coverage. Visual assessment of the annual bluegrass population was determined before the initial spring methiozolin and nitrogen treatments in 2015, and every two weeks after the initial application in 2014 and 2015. Grid counting was conducted before the initial treatment and every month after that using an 11 by 11 (totally 121 intersections) grid. Unlike the voids coverage, the data of annual bluegrass population was not transformed. The percent coverage of live annual bluegrass stands for the annual bluegrass population data. The grid counting was conducted monthly with a total of three readings after the first application of spring methiozolin and nitrogen in each year.

Table 2.14 shows the effects of methiozolin, nitrogen rates and fertilizing frequency on the visual assessment of annual bluegrass population in 2014. As the table shows, there were significant differences between methiozolin treatments four WAIT (p = 0.0456, May 13, 2014) and six WAIT (p = 0.0096, May 28, 2014). There was no significant differences between nitrogen rates or different fertilizing frequencies in 2014. There were also no significant interactions between any factors on the changes of visual assessment of annual bluegrass population in 2014 (Table 2.14). In 2015, the significant difference (p ≤ 0.05) in the annual bluegrass population between methiozolin treated and untreated plots occurred later than 2014. No significant effects of methiozolin was
there until ten WAIT (Table 2.15). Unlike the ANOVA results in 2014, there was significant effects from nitrogen rates ($p \leq 0.05$) from two WAIT to ten WAIT in 2015. Significant differences were also found between fertilizing frequencies on May 26, 2015 ($p = 0.0018$) and June 23, 2015 ($p = 0.0027$). As in 2014, there was no significant interactions detected between any of the factors in 2015. Thus, the visual assessment of annual bluegrass population was compared between methiozolin treatments, and then between nitrogen rates at each fertilizing frequencies for both years.

Figure 2.3 shows the visual assessment data for the visual assessment of annual bluegrass population as affected by methiozolin treated and methiozolin untreated plots from 2 WAIT to 12 WAIT in 2014 and 2015. At two WAIT, the annual bluegrass population in 2014 was much higher than the annual bluegrass population in 2015 according to the visual assessment. There was then a great decrease on the annual bluegrass population, and by the time of four WAIT, the annual bluegrass population in spring methiozolin treated plots was lower than the annual bluegrass population in 2015 at that time and also significantly lower than plots with no methiozolin in the spring of 2014. After eight WAIT, there was no statistic significant difference between methiozolin treatments in 2014, but the differences of the annual bluegrass population between methiozolin and no methiozolin plots were still huge. Plots with no spring application of methiozolin had an annual bluegrass population around 5%, while the number was below 1% on spring methiozolin treated plots in 2014. In 2015, the annual bluegrass populations were almost the same two WAIT. With more methiozolin applications, the annual bluegrass population decreased more compared with plots without spring methiozolin treatments. After the fourth and also the last application of spring methiozolin application
at six WAIT, there was an increase in annual bluegrass population on non-methiozolin treatments. On the other hand, the population remained the same over time in methiozolin treated plots, which leaded to the significant ANOVA results between methiozolin treatments in 2015.

Figure 2.34 shows the effects of nitrogen rates on the visual assessment of annual bluegrass population at each fertilizing frequency two WAIT. The annual bluegrass population affected by nitrogen rates are very irregular over different fertilizing frequencies at this time in 2014. While in 2015, the annual bluegrass population decreased with higher nitrogen rates. Noticed that plots in Figure 2.34 (c), which received two applications of nitrogen treatments has more decrease in the annual bluegrass population than those in (a) and (b) which received only one nitrogen application at each rate at two WAIT in 2015.

Figure 2.35 shows the annual bluegrass population four WAIT affected by nitrogen rates and fertilizing frequencies. Unlike two WAIT, the annual bluegrass population from 2014 started to decrease with increasing nitrogen rate at all frequencies at this time. With only one application completed, nitrogen treatments which were fertilized once per month [Figure 2.35 (a)] showed the same relative difference between each nitrogen rate as Figure 2.34 (a), but with lower annual bluegrass population. In Figure 2.34 (b), 12.2 kg N ha⁻¹ treatment had the lowest annual bluegrass population in both years and In Figure 2.34 (c), 24.4 kg N ha⁻¹ treatment resulted to the lowest annual bluegrass population. Noticeably, with 24.4 kg N ha⁻¹ four times per month, the annual bluegrass population already reached zero at four WAIT in 2014[Figure 2.35 (c)].
Compared between fertilizing frequencies, the 6.1 kg N ha\(^{-1}\) had more decrease on annual bluegrass population when applied at a higher frequency.

In Figure 2.36 (a), there was a greater decrease in the annual bluegrass population two weeks after the second nitrogen application with treatments at the once per month fertilizing frequency. However, the relative difference between each nitrogen rate remained the same as the data from the two figures above [Figure 2.34 (a) and Figure 2.35 (a)]. The annual bluegrass population under both 6.1 kg N ha\(^{-1}\) and 24.4 kg N ha\(^{-1}\) treatments reached zero at this time [Figure 2.36 (a)]. The annual bluegrass population under the 12.2 kg N ha\(^{-1}\) was even higher than no nitrogen control, but it started with a higher annual bluegrass population according to the data at two WAIT [Figure 2.34 (a)].

In 2015, the nitrogen rate with the lowest annual bluegrass population when applied once per month was still 12.2 kg N ha\(^{-1}\) [Figure 2.36 (a)]. For nitrogen applied twice per month, there was greater decrease in the annual bluegrass population with higher nitrogen applied in 2015 and 12.2 kg N ha\(^{-1}\) twice per month had zero annual bluegrass population in 2014 at six WAIT [Figure 2.36 (b)]. With fertilizer every week [Figure 2.36 (c)], the annual bluegrass population continued to decrease with 12.2 kg N ha\(^{-1}\), and it became lower than 24.4 kg N ha\(^{-1}\) in 2015, and both of these higher nitrogen rate treatments had significantly lower annual bluegrass population than no nitrogen control and 6.1 kg N ha\(^{-1}\) (Table 2.15).

Figure 2.37 is eight WAIT, and at this point of time, the promoting effect of higher nitrogen program on the annual bluegrass re-encroachment started to show. The data from 2014 shows less decrease on annual bluegrass population compared with
Figure 2.36. There is even an increase on annual bluegrass population with 12.2 kg N ha\(^{-1}\) and 24.4 kg N ha\(^{-1}\) on all three fertilizing frequencies. The annual bluegrass population eight WAIT in 2015 was similar to six WAIT in 2015 [Figure 2.36], but with a little increase in annual bluegrass population at once per month fertilizing frequency. When fertilized twice per month, there is no significant difference between the control group and 6.1 kg N ha\(^{-1}\), but the annual bluegrass population decreased significantly with higher nitrogen rate [Figure 2.37 (b)]. When fertilized every week, the annual bluegrass population decreased more with higher nitrogen rates, but 12.2 kg N ha\(^{-1}\) is similar to 24.4 kg N ha\(^{-1}\).

Figure 2.38 shows the visual assessment of annual bluegrass population affected by nitrogen rates at each fertilizing frequency ten weeks after the initial treatment. Compared to six WAIT and eight WAIT, 24.4 kg N ha\(^{-1}\) applied once per month still helps with the decrease of annual bluegrass population [Figure 2.38 (a)], however there is an increase of annual bluegrass population with 24.4 kg N ha\(^{-1}\) applied twice per month and four times per month [Figure 2.38 (b) & (c)] in both 2014 and 2015.

This effects of high nitrogen on annual bluegrass re-encroachment continues for two more weeks. In Figure 2.39 (a), the annual bluegrass population under 24.4 kg N ha\(^{-1}\) once per month in 2014 went back to zero, but there is an increase in annual bluegrass population under 24.4 kg N ha\(^{-1}\) once per month in 2015 and all the other frequencies at this nitrogen rate in both years. The nitrogen rate helpful for continuous suppression on annual bluegrass population is 6.1 kg N ha\(^{-1}\) every week, 12.2 kg N ha\(^{-1}\) twice per month and 12.2 kg N ha\(^{-1}\) every week.
The grid counting annual bluegrass population is also conducted to study the effects of spring methiozolin on the control of annual bluegrass and the effects of nitrogen strategies on the suppression of annual bluegrass re-encroachment. According to the ANOVA results in Table 2.16 and Table 2.17, there is significant difference between methiozolin treated and untreated plots eight WAIT (p = 0.0479, June 12, 2014), but no significant result found between spring methiozolin treatments in 2015. Unlike the visual assessment of annual bluegrass population data, there is no significant effects from nitrogen rates or fertilizing frequencies in both years, and there is also no significant interactions between any of the factors in the grid counting data.

Figure 2.40 shows the effects of spring methiozolin on the grid counting annual bluegrass population. There are similarities to the visual assessment data, such as no methiozolin control in 2014 has increase on the annual bluegrass population and methiozolin treated plots from 2014 has the most decrease of annual bluegrass population. The difference is that the no methiozolin control in 2015 has a negative change of annual bluegrass population according to the grid counting results, while in Figure 2.33 there is an increase of annual bluegrass population at the end of the experiment period compared to the original annual bluegrass population at the beginning of the experiment. Over all, the same conclusion can be made as the visual assessment of annual bluegrass population that the plots with applications of spring methiozolin has a significant decrease on the annual bluegrass population compared with plots with no spring methiozolin.
Figure 2.41 shows the grid counting annual bluegrass population four WAIT in 2014 and 2015. With only one application of nitrogen, there is no big difference between nitrogen rates in both 2014 and 2015 [Figure 2.41 (a)]. With two applications of nitrogen, there is significant difference between nitrogen rates applied at two-week intervals in 2014 similar to the visual assessment data in Figure 2.35 (b), that 12.2 kg N ha\(^{-1}\) at this frequency has the lowest annual bluegrass population. However, the grid counting results from 2015 is not able to show the same effect on annual bluegrass population as the visual data. When fertilized weekly, the annual bluegrass population decreases with higher nitrogen rates in 2014, and also in 2015 except for 6.1 kg N ha\(^{-1}\).

In Figure 2.42 (a), two applications have been done for plots with fertilizing frequency once per month. The annual bluegrass population decreases with higher nitrogen rates in 2015, and in 2014, 6.1 kg N ha\(^{-1}\) and 24.4 kg N ha\(^{-1}\)s had the most decrease on annual bluegrass population. In Figure 2.42 (b), after four applications of nitrogen at two weeks interval, 24.4 kg N ha\(^{-1}\) has the most change in annual bluegrass population than all the other nitrogen treatments, while 12.2 kg N ha\(^{-1}\) resulted to the lowest annual bluegrass population at eight WAIT in 2015. In 2014, the annual bluegrass population under no nitrogen and 6.1 kg N ha\(^{-1}\) decreased since four WAIT, while 12.2 kg N ha\(^{-1}\) has no effects on annual bluegrass population from four WAIT to eight WAIT and 24.4 kg N ha\(^{-1}\) increased annual bluegrass population. When it comes to weekly nitrogen application, the annual bluegrass population increased with higher nitrogen rates eight WAIT in 2014, which is the opposite compared with four WAIT in Figure 2.41 (c). As to 2015, 12.2 kg N ha\(^{-1}\) had the lowest annual bluegrass population at this point, but
24.4 kg N ha\(^{-1}\) applied every week still had the highest annual bluegrass population, even higher than the no nitrogen control [Figure 2.42 (c)].

In Figure 2.43, the nitrogen strategy with the most annual bluegrass population decrease at twelve WAIT is very similar to the visual assessment results: 6.1 kg N ha\(^{-1}\) once per month, 12.2 kg N ha\(^{-1}\) twice per month in 2014; 24.4 kg N ha\(^{-1}\) once per month, 12.2 kg N ha\(^{-1}\) twice per month and four times per month in 2015 are the nitrogen programs with the lowest annual bluegrass population at each frequency in each year. The effects of high nitrogen program on the encouraging of the annual bluegrass re-encroachment is still noticeable like the visual assessment of annual bluegrass population, especially 24.4 kg N ha\(^{-1}\) which has an increase on annual bluegrass population compared with the data four weeks before (Figure 2.42) at all fertilizing frequencies.

In conclusion, due to the limitation of the method of grid counting, the grid counting results of annual bluegrass population is not as representative as the visual assessment data when there is a relatively low population of annual bluegrass. In spite of the limitation of the grid to cover the entire plot, both the visual assessment and grid counting has proved significant effects of spring methiozolin on the decrease of annual bluegrass population in both years. The role of nitrogen on the decrease of annual bluegrass population is more complicated than methiozolin. Higher nitrogen rates at a higher application frequency is better for annual bluegrass control during early spring, however with the temperature raises higher nitrogen programs has some negative effects on the growth of creeping bentgrass which leaves chances for annual bluegrass to encroach. Considering the results from both visual assessment and the grid counting, 6.1
kg N ha\(^{-1}\) every week and 12.2 kg N ha\(^{-1}\) every other week are the best nitrogen strategies to discourage the annual bluegrass encroachment during the spring recovery period from a successful fall methiozolin control.

Conclusions

According to the NDVI, green index and visual assessment data, the color of creeping bentgrass is mainly affected by nitrogen rate. In a normal year like 2014, the nitrogen programs of 24.4 kg N ha\(^{-1}\) once a month or twice a month and 12.2 kg N ha\(^{-1}\) every week provide darker creeping bentgrass color. While in a warmer year like 2015, less nitrogen application is needed to achieve high creeping bentgrass color and fast green-up speed. In this case, the best spring nitrogen fertilizing programs are 12.2 kg N ha\(^{-1}\) twice per month or 6.1 kg N ha\(^{-1}\) four times per month. Methiozolin also has inconsistent performance on creeping bentgrass color. Spring applications of methiozolin at the rate of 0.53 kg a.i. ha\(^{-1}\) had significant negative effects on the color of creeping bentgrass during the six weeks of application in 2014, but no negative effect from methiozolin on the spring color of creeping bentgrass was found at all in 2015.

Like the negative effects of spring methiozolin on the color of creeping bentgrass, methiozolin also has significant negative effects on the recovery of creeping bentgrass in 2014, and not in 2015. Nitrogen rate is still the main factor on the recovery rate of creeping bentgrass. Under cool weather condition, 12.2 kg N ha\(^{-1}\) and 24.4 kg N ha\(^{-1}\) every week or 24.4 kg N ha\(^{-1}\) every other week has the most recovery of creeping bentgrass from voids. Under a high temperature condition with higher burning potential like the situation in 2015, lower nitrogen rates are better to creeping bentgrass recovery,
by lowering the chance of the chemical stress. In this case, both 6.1 kg N ha\(^{-1}\) every week and 12.2 kg N ha\(^{-1}\) every other week results to acceptable creeping bentgrass recovery after a successful methiozolin fall control on annual bluegrass.

Even though after the fall applications of methiozolin the population of annual bluegrass remaining on the green is very low, spring application of methiozolin still has a significant effect on the further decrease of annual bluegrass population. Compared with the no spring methiozolin group, four applications of methiozolin in the spring can effectively prevent the appearance of new annual bluegrass seedlings and suppress the annual bluegrass patches left after the fall treatment from growing bigger. The role of nitrogen on the decrease of annual bluegrass population is more complicated than methiozolin. Higher nitrogen rates at a higher application frequency is better for annual bluegrass control during early spring. However with the temperature raises, higher nitrogen programs have some negative effects on the growth of creeping bentgrass which leaves chances for annual bluegrass to encroach. Considering the results from both visual assessment and the grid counting, 6.1 kg N ha\(^{-1}\) every week and 12.2 kg N ha\(^{-1}\) every other week is the best nitrogen strategies to discourage the annual bluegrass encroachment during the spring recovery period after a successful fall methiozolin control.
Table 2.1. All treatments of spring application of nitrogen and methiozolin on annual bluegrass control on golf greens after fall treatment.

<table>
<thead>
<tr>
<th>Nitrogen Rate (kg N ha⁻¹)</th>
<th>0 (N0)</th>
<th>6.1 (N1)</th>
<th>12.2 (N2)</th>
<th>24.4 (N4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No spring methiozolin (M0)†</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fertilizing Frequency (times/month)¹</td>
<td>1 (F1)</td>
<td>M0N0F1</td>
<td>M0N1F1</td>
<td>M0N2F1</td>
</tr>
<tr>
<td></td>
<td>2 (F2)</td>
<td>M0N0F2</td>
<td>M0N1F2</td>
<td>M0N2F2</td>
</tr>
<tr>
<td></td>
<td>4 (F4)</td>
<td>M0N0F4</td>
<td>M0N1F4</td>
<td>M0N2F4</td>
</tr>
<tr>
<td>Spring Methiozolin (M1)‡</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fertilizing Frequency (times/month)</td>
<td>1 (F1)</td>
<td>M1N0F1</td>
<td>M1N1F1</td>
<td>M1N2F1</td>
</tr>
<tr>
<td></td>
<td>2 (F2)</td>
<td>M1N0F2</td>
<td>M1N1F2</td>
<td>M1N2F2</td>
</tr>
<tr>
<td></td>
<td>4 (F4)</td>
<td>M1N0F4</td>
<td>M1N1F4</td>
<td>M1N2F4</td>
</tr>
</tbody>
</table>

† All the plots were treated with three applications of methiozolin at the rate of 0.53 kg a.i. ha⁻¹ as fall methiozolin treatments in the previous year.
‡ Spring methiozolin treatments as the main-plot was applied at the rate of 0.53 kg a.i. ha⁻¹ at two-week intervals (twice per month) according to the protocol.
¹ Fertilizer frequency with once per month, twice per month, and four times per month stands for nitrogen application every month, every two weeks, and every week, respectively. Fertilizing frequencies and nitrogen rates were randomized jointly in each main-plot as split-plots.
Table 2.2. Application dates and rates of methiozolin fall treatments to the experimental area on a practice putting green in the field preparation stage in 2013 and 2014.

<table>
<thead>
<tr>
<th>Application dates and rates of methiozolin in each year</th>
<th>2013</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 October ‡, 0.53 kg a.i. ha⁻¹‡</td>
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† All the fall applications of methiozolin was initiated between late September and early October; and ended before the end of October according to the protocol.
‡ Three applications of methiozolin at the rate 0.53 kg a.i. ha⁻¹ was made according to the methiozolin fall application protocol.
<table>
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<th>Year</th>
<th>Date</th>
<th>Air temp. (high/low, C)</th>
<th>M1 (kg a.i. ha$^{-1}$)</th>
<th>N1 (kg N ha$^{-1}$)</th>
<th>N2 (kg N ha$^{-1}$)</th>
<th>N4 (kg N ha$^{-1}$)</th>
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</thead>
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<td>F1</td>
<td>F2</td>
<td>F4</td>
<td>F1</td>
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<td>6.1</td>
<td>6.1</td>
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<td>8 May</td>
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<td>6.1</td>
<td>6.1</td>
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<td>20.3/11.0</td>
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<td>6.1</td>
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<td>6.1</td>
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<tr>
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<td>28.6/21.3</td>
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<td>6.1</td>
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<td>6.1</td>
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<td></td>
<td></td>
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Table 2.4. NDVI of creeping bentgrass influenced by methiozolin, nitrogen rates and fertilizing frequency on annual bluegrass control on golf greens after fall treatment, 2014.

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<th>8 WAIT</th>
<th>10 WAIT</th>
<th>12 WAIT</th>
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<td></td>
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<tr>
<td>0 kg a.i. ha(^{-1})</td>
<td>0.587a†</td>
<td>0.680a</td>
<td>0.715a</td>
<td>0.719a</td>
<td>0.750a</td>
<td>0.759a</td>
<td>0.718a</td>
</tr>
<tr>
<td>0.53 kg a.i. ha(^{-1})</td>
<td>0.588a</td>
<td>0.687b</td>
<td>0.678b</td>
<td>0.687b</td>
<td>0.736b</td>
<td>0.753a</td>
<td>0.718a</td>
</tr>
<tr>
<td>Nitrogen rates</td>
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<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>0 kg N ha(^{-1})</td>
<td>0.590a</td>
<td>0.630a</td>
<td>0.657a</td>
<td>0.661a</td>
<td>0.715a</td>
<td>0.744a</td>
<td>0.711a</td>
</tr>
<tr>
<td>6.1 kg N ha(^{-1})</td>
<td>0.584a</td>
<td>0.663b</td>
<td>0.695b</td>
<td>0.699b</td>
<td>0.740b</td>
<td>0.753b</td>
<td>0.718ab</td>
</tr>
<tr>
<td>12.2 kg N ha(^{-1})</td>
<td>0.586a</td>
<td>0.683c</td>
<td>0.709c</td>
<td>0.723c</td>
<td>0.753c</td>
<td>0.761c</td>
<td>0.718ab</td>
</tr>
<tr>
<td>24.4 kg N ha(^{-1})</td>
<td>0.589a</td>
<td>0.698c</td>
<td>0.724d</td>
<td>0.729c</td>
<td>0.764d</td>
<td>0.766c</td>
<td>0.726b</td>
</tr>
<tr>
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<tr>
<td>1 time/month</td>
<td>0.587a</td>
<td>0.658a</td>
<td>0.682a</td>
<td>0.693a</td>
<td>0.739a</td>
<td>0.754a</td>
<td>0.717a</td>
</tr>
<tr>
<td>2 times/month</td>
<td>0.593a</td>
<td>0.674b</td>
<td>0.702b</td>
<td>0.705ab</td>
<td>0.744a</td>
<td>0.760a</td>
<td>0.721a</td>
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<tr>
<td>4 times/month</td>
<td>0.583a</td>
<td>0.674b</td>
<td>0.704b</td>
<td>0.711b</td>
<td>0.745a</td>
<td>0.755a</td>
<td>0.716a</td>
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ANOVA results\(^{‡}\):

<table>
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<tr>
<th></th>
<th>Methiozolin(^{†})</th>
<th>Nitrogen rates (^{†})</th>
<th>Fertilizing Frequency (^{†})</th>
<th>M*N</th>
<th>M+F</th>
<th>N+F</th>
<th>M*N+F (^{‡})</th>
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</thead>
<tbody>
<tr>
<td>Methiozolin (^{†})</td>
<td>0.9456</td>
<td>0.8625</td>
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<td>0.6244</td>
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</tr>
<tr>
<td>Nitrogen rates (^{†})</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Fertilizing Frequency (^{†})</td>
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<td>0.0035</td>
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<td>0.5365</td>
</tr>
<tr>
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<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.0276</td>
<td>0.0276</td>
<td>0.0276</td>
<td>0.0311</td>
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<tr>
<td>M+F</td>
<td>0.0267</td>
<td>0.2604</td>
<td>0.3658</td>
<td>0.5812</td>
<td>0.5812</td>
<td>0.5812</td>
<td>0.5174</td>
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<tr>
<td>N+F</td>
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<td>0.0202</td>
<td>0.3658</td>
<td>0.9714</td>
<td>0.9714</td>
<td>0.9714</td>
<td>0.9714</td>
</tr>
</tbody>
</table>

\(^{†}\) Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.

\(^{‡}\) For the ANOVA test, block*methiozolin interaction was used as the error term for the main-plot and M*N*block + M*F*block + N*F*block + M*N*F*block interaction was used as the error term for the split-plot.
Table 2.5. NDVI of creeping bentgrass influenced by methiozolin, nitrogen rates and fertilizing frequency on annual bluegrass control on golf greens after fall treatment, 2015.

<table>
<thead>
<tr>
<th></th>
<th>0 WAIT</th>
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<th>4 WAIT</th>
<th>6 WAIT</th>
<th>8 WAIT</th>
<th>10 WAIT</th>
<th>12 WAIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methiozolin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 kg a.i. ha⁻¹</td>
<td>0.651a†</td>
<td>0.737a</td>
<td>0.763a</td>
<td>0.734a</td>
<td>0.764a</td>
<td>0.735a</td>
<td>0.756a</td>
</tr>
<tr>
<td>0.53 kg a.i. ha⁻¹</td>
<td>0.665a</td>
<td>0.738a</td>
<td>0.759a</td>
<td>0.731a</td>
<td>0.765a</td>
<td>0.734a</td>
<td>0.757a</td>
</tr>
<tr>
<td>Nitrogen rates</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 kg N ha⁻¹</td>
<td>0.657a</td>
<td>0.731a</td>
<td>0.757a</td>
<td>0.721a</td>
<td>0.764b</td>
<td>0.736a</td>
<td>0.757a</td>
</tr>
<tr>
<td>6.1 kg N ha⁻¹</td>
<td>0.653a</td>
<td>0.737a</td>
<td>0.760a</td>
<td>0.732b</td>
<td>0.771a</td>
<td>0.737a</td>
<td>0.759a</td>
</tr>
<tr>
<td>12.2 kg N ha⁻¹</td>
<td>0.656a</td>
<td>0.736a</td>
<td>0.763a</td>
<td>0.740b</td>
<td>0.766ab</td>
<td>0.741a</td>
<td>0.759a</td>
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<tr>
<td>24.4 kg N ha⁻¹</td>
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<td>0.764a</td>
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<td>0.752a</td>
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<tr>
<td>Fertilizing frequency</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 time/month</td>
<td>0.654a</td>
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<td>0.761a</td>
<td>0.730a</td>
<td>0.769a</td>
<td>0.739a</td>
<td>0.761a</td>
</tr>
<tr>
<td>2 times/month</td>
<td>0.650a</td>
<td>0.736a</td>
<td>0.760a</td>
<td>0.732ab</td>
<td>0.764ab</td>
<td>0.735ab</td>
<td>0.758a</td>
</tr>
<tr>
<td>4 times/month</td>
<td>0.656a</td>
<td>0.736a</td>
<td>0.761a</td>
<td>0.737b</td>
<td>0.761b</td>
<td>0.729b</td>
<td>0.751b</td>
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</table>

ANOVA results‡

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<td>0.0017</td>
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<td>M*N</td>
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† Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
‡ For the ANOVA test, block*methiozolin interaction was used as the error term for the main-plot and M*N*block + M*F*block + N*F*block + M*N*F*block interaction was used as the error term for the split-plot.
Table 2.6. Green Index of creeping bentgrass influenced by methiozolin, nitrogen rates and fertilizing frequency on annual bluegrass control on golf greens after fall treatment, 2014.

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<th>6 WAIT</th>
<th>8 WAIT</th>
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<th>12 WAIT</th>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 kg a.i. ha(^{-1})</td>
<td>6.36a(^{†})</td>
<td>6.83a</td>
<td>7.07a</td>
<td>7.09a</td>
<td>7.26a</td>
<td>7.40a</td>
<td>7.04a</td>
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<td>6.68b</td>
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<td>7.18a</td>
<td>7.35a</td>
<td>7.04a</td>
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<td></td>
</tr>
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<td>0 kg N ha(^{-1})</td>
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<td>6.73b</td>
<td>6.93b</td>
<td>6.93b</td>
<td>7.20b</td>
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<td>7.06bc</td>
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<tr>
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<td>7.11c</td>
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<tr>
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<td>6.81a</td>
<td>6.90a</td>
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<td>7.03b</td>
<td>7.24b</td>
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<td>7.00b</td>
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**ANOVA results\(^{‡}\)**

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<tr>
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<th>F-value</th>
<th>P-value</th>
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<tbody>
<tr>
<td>Methiozolin</td>
<td>0.9104</td>
<td>0.0071</td>
</tr>
<tr>
<td>Nitrogen rates</td>
<td>0.8266</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Fertilizing Frequency</td>
<td>0.0732</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>M*N</td>
<td>0.0687</td>
<td>0.7617</td>
</tr>
<tr>
<td>M*F</td>
<td>0.8689</td>
<td>0.5071</td>
</tr>
<tr>
<td>N*F</td>
<td>0.1760</td>
<td>0.0013</td>
</tr>
<tr>
<td>M<em>N</em>F</td>
<td>0.6456</td>
<td>0.1895</td>
</tr>
</tbody>
</table>

\(^{†}\) Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.

\(^{‡}\) For the ANOVA test, block*methiozolin interaction was used as the error term for the main-plot and M*N*block + M*F*block + N*F*block + M*N*F*block interaction was used as the error term for the split-plot.
Table 2.7. Green Index of creeping bentgrass influenced by methiozolin, nitrogen rates and fertilizing frequency on annual bluegrass control on golf greens after fall treatment, 2015.

<table>
<thead>
<tr>
<th>Methiozolin</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 WAIT</td>
</tr>
<tr>
<td>0 kg a.i. ha⁻¹</td>
<td>6.64a†</td>
</tr>
<tr>
<td>0.53 kg a.i. ha⁻¹</td>
<td>6.59a</td>
</tr>
<tr>
<td>Nitrogen rates</td>
<td></td>
</tr>
<tr>
<td>0 kg N ha⁻¹</td>
<td>6.63a</td>
</tr>
<tr>
<td>6.1 kg N ha⁻¹</td>
<td>6.57a</td>
</tr>
<tr>
<td>12.2 kg N ha⁻¹</td>
<td>6.62a</td>
</tr>
<tr>
<td>24.4 kg N ha⁻¹</td>
<td>6.63a</td>
</tr>
<tr>
<td>Fertilizing frequency</td>
<td></td>
</tr>
<tr>
<td>1 time/month</td>
<td>6.62a</td>
</tr>
<tr>
<td>2 times/month</td>
<td>6.59a</td>
</tr>
<tr>
<td>4 times/month</td>
<td>6.63a</td>
</tr>
</tbody>
</table>

ANOV A results‡

| Methiozolin          | 0.2486 | 0.2757 | 0.0064 | 0.8172 | 0.3101 | 0.7176 | 0.5791 |
| Nitrogen rates       | 0.4215 | 0.0007 | 0.3208 | 0.0005 | 0.2832 | 0.5970 | 0.7889 |
| Fertilizing Frequency| 0.5430 | 0.0833 | 0.2657 | 0.7674 | 0.1009 | 0.0272 | 0.0502 |
| M*N                  | 0.6496 | 0.8867 | 0.8946 | 0.9778 | 0.7420 | 0.6000 | 0.4466 |
| M*F                  | 0.0122 | 0.8775 | 0.6956 | 0.5619 | 0.0970 | 0.5563 | 0.6749 |
| N*F                  | 0.0246 | 0.4689 | 0.0290 | 0.7108 | 0.3861 | 0.7291 | 0.3072 |
| M*N*F                | 0.9189 | 0.8816 | 0.9716 | 0.6235 | 0.5761 | 0.9250 | 0.0329 |

† Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
‡ For the ANOVA test, block*methiozolin interaction was used as the error term for the main-plot and M*N*block + M*F*block + N*F*block + M*N*F*block interaction was used as the error term for the split-plot.
Table 2.8. Visual assessments of creeping bentgrass color influenced by methiozolin, nitrogen rates and fertilizing frequency on annual bluegrass control on golf greens after fall treatment, 2014.

<table>
<thead>
<tr>
<th></th>
<th>Dates</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 WAIT</td>
<td>2 WAIT</td>
<td>4 WAIT</td>
<td>6 WAIT</td>
<td>8 WAIT</td>
<td>10 WAIT</td>
<td>12 WAIT</td>
</tr>
<tr>
<td>Methiozolin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 kg a.i. ha⁻¹</td>
<td>6.0a</td>
<td>6.6a</td>
<td>6.8a</td>
<td>7.0a</td>
<td>7.3a</td>
<td>7.3a</td>
<td>6.9a</td>
</tr>
<tr>
<td>0.53 kg a.i. ha⁻¹</td>
<td>6.0a</td>
<td>6.5a</td>
<td>6.6b</td>
<td>7.0a</td>
<td>7.4a</td>
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<tr>
<td>Nitrogen rates</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 kg N ha⁻¹</td>
<td>6.0a</td>
<td>5.0a</td>
<td>5.0a</td>
<td>5.2a</td>
<td>5.8a</td>
<td>6.0a</td>
<td>6.1a</td>
</tr>
<tr>
<td>6.1 kg N ha⁻¹</td>
<td>6.0a</td>
<td>6.4b</td>
<td>6.7b</td>
<td>7.0b</td>
<td>7.4b</td>
<td>7.3b</td>
<td>6.8b</td>
</tr>
<tr>
<td>12.2 kg N ha⁻¹</td>
<td>6.0a</td>
<td>6.9c</td>
<td>7.3c</td>
<td>7.5c</td>
<td>7.7b</td>
<td>7.7c</td>
<td>7.1c</td>
</tr>
<tr>
<td>24.4 kg N ha⁻¹</td>
<td>6.0a</td>
<td>7.8d</td>
<td>7.8d</td>
<td>8.3d</td>
<td>8.4c</td>
<td>8.2d</td>
<td>7.4d</td>
</tr>
<tr>
<td>Fertilizing frequency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 time/month</td>
<td>6.0a</td>
<td>6.4a</td>
<td>6.0a</td>
<td>6.4a</td>
<td>6.9a</td>
<td>6.7a</td>
<td>6.5a</td>
</tr>
<tr>
<td>2 times/month</td>
<td>6.0a</td>
<td>6.4a</td>
<td>6.8b</td>
<td>7.1b</td>
<td>7.4b</td>
<td>7.5b</td>
<td>6.9b</td>
</tr>
<tr>
<td>4 times/month</td>
<td>6.0a</td>
<td>6.9b</td>
<td>7.3c</td>
<td>7.5c</td>
<td>7.7c</td>
<td>7.7c</td>
<td>7.1c</td>
</tr>
</tbody>
</table>

ANOVA results

<table>
<thead>
<tr>
<th></th>
<th>Methiozolin</th>
<th>Nitrogen rates</th>
<th>Fertilizing Frequency</th>
<th>M*N</th>
<th>M*F</th>
<th>N*F</th>
<th>M<em>N</em>F</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>-</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
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<td>&lt;.0001</td>
<td>&lt;.001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Fertilizing Frequency</td>
<td>-</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
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</tr>
<tr>
<td>M*N</td>
<td>0.0551</td>
<td>0.2928</td>
<td>0.3051</td>
<td>0.5753</td>
<td>0.9421</td>
<td>0.0794</td>
<td></td>
</tr>
<tr>
<td>M*F</td>
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<td>0.3141</td>
<td>0.8199</td>
<td>0.9309</td>
<td>0.5995</td>
<td>0.7283</td>
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<tr>
<td>N*F</td>
<td>-</td>
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<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>M<em>N</em>F</td>
<td>-</td>
<td>0.7133</td>
<td>0.4335</td>
<td>0.5420</td>
<td>0.9511</td>
<td>0.3424</td>
<td>0.4194</td>
</tr>
</tbody>
</table>

† Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
‡ For the ANOVA test, block*methiozolin interaction was used as the error term for the main-plot and M*N*block + M*F*block + N*F*block + M*N*F*block interaction was used as the error term for the split-plot.
Table 2.9. Visual assessments of creeping bentgrass color influenced by methiozolin, nitrogen rates and fertilizing frequency on annual bluegrass control on golf greens after fall treatment, 2015.

<table>
<thead>
<tr>
<th>Methiozolin</th>
<th>Dates</th>
<th>0 WAIT</th>
<th>2 WAIT</th>
<th>4 WAIT</th>
<th>6 WAIT</th>
<th>8 WAIT</th>
<th>10 WAIT</th>
<th>12 WAIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 kg a.i. ha⁻¹</td>
<td></td>
<td>7.4a</td>
<td>7.6a</td>
<td>7.6a</td>
<td>7.8a</td>
<td>7.5a</td>
<td>7.6a</td>
<td>7.8a</td>
</tr>
<tr>
<td>0.53 kg a.i. ha⁻¹</td>
<td></td>
<td>7.4a</td>
<td>7.6a</td>
<td>7.8a</td>
<td>7.8a</td>
<td>7.6a</td>
<td>7.6a</td>
<td>7.8a</td>
</tr>
<tr>
<td>Nitrogen rates</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 kg N ha⁻¹</td>
<td></td>
<td>7.4a</td>
<td>6.3a</td>
<td>6.2a</td>
<td>6.4a</td>
<td>6.5a</td>
<td>6.9a</td>
<td>7.6a</td>
</tr>
<tr>
<td>6.1 kg N ha⁻¹</td>
<td></td>
<td>7.4a</td>
<td>7.7b</td>
<td>7.9b</td>
<td>8.0b</td>
<td>8.1c</td>
<td>8.0c</td>
<td>8.0c</td>
</tr>
<tr>
<td>12.2 kg N ha⁻¹</td>
<td></td>
<td>7.4a</td>
<td>8.0c</td>
<td>8.2c</td>
<td>8.3c</td>
<td>8.3c</td>
<td>8.0c</td>
<td>7.9c</td>
</tr>
<tr>
<td>24.4 kg N ha⁻¹</td>
<td></td>
<td>7.4a</td>
<td>8.4d</td>
<td>8.5d</td>
<td>8.6d</td>
<td>7.2b</td>
<td>7.5b</td>
<td>7.8b</td>
</tr>
<tr>
<td>Fertilizing frequency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 time/month</td>
<td></td>
<td>7.4a</td>
<td>7.5a</td>
<td>7.4a</td>
<td>7.6a</td>
<td>7.7a</td>
<td>7.7a</td>
<td>7.8ab</td>
</tr>
<tr>
<td>2 times/month</td>
<td></td>
<td>7.4a</td>
<td>7.6a</td>
<td>7.8b</td>
<td>7.7a</td>
<td>7.7a</td>
<td>7.7ab</td>
<td>7.9a</td>
</tr>
<tr>
<td>4 times/month</td>
<td></td>
<td>7.5a</td>
<td>7.6a</td>
<td>7.9b</td>
<td>8.1b</td>
<td>7.2b</td>
<td>7.5b</td>
<td>7.7b</td>
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</table>

ANOVA results

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<tr>
<th></th>
<th>F</th>
<th>P-value</th>
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</thead>
<tbody>
<tr>
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<td>0.2697</td>
<td>0.6710</td>
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<td>Nitrogen rates</td>
<td>0.6827</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Fertilizing Frequency</td>
<td>0.3092</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>M*N</td>
<td>0.8952</td>
<td>0.0010</td>
</tr>
<tr>
<td>M*F</td>
<td>0.7413</td>
<td>0.1669</td>
</tr>
<tr>
<td>N*F</td>
<td>0.9747</td>
<td>0.1669</td>
</tr>
<tr>
<td>M<em>N</em>F</td>
<td>0.3748</td>
<td>0.0236</td>
</tr>
</tbody>
</table>

†Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.

‡For the ANOVA test, block*methiozolin interaction was used as the error term for the main-plot and M*N*block + M*F*block + N*F*block + M*N*F*block interaction was used as the error term for the split-plot.
Table 2.10. Changes of percent coverage visual assessment of voids influenced by methiozolin, nitrogen rates and fertilizing frequency on annual bluegrass control on golf greens after fall treatment, 2014.

<table>
<thead>
<tr>
<th>Methiozolin</th>
<th>(0 WAIT)</th>
<th>2 WAIT</th>
<th>4 WAIT</th>
<th>6 WAIT</th>
<th>8 WAIT</th>
<th>10 WAIT</th>
<th>12 WAIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 kg a.i. ha⁻¹</td>
<td>(31.25a)</td>
<td>-21.94a</td>
<td>-24.64</td>
<td>-27.19</td>
<td>-28.58</td>
<td>-29.81</td>
<td>-30.67</td>
</tr>
<tr>
<td>0.53 kg a.i. ha⁻¹</td>
<td>(31.11a)</td>
<td>-21.11</td>
<td>-21.06</td>
<td>-22.75</td>
<td>-21.58</td>
<td>-25.22</td>
<td>-27.28</td>
</tr>
<tr>
<td>Nitrogen rates</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 kg N ha⁻¹</td>
<td>(29.44a)</td>
<td>-21.94a</td>
<td>-20.11</td>
<td>-23.33</td>
<td>-23.94</td>
<td>-25.39</td>
<td>-27.33</td>
</tr>
<tr>
<td>12.2 kg N ha⁻¹</td>
<td>(31.39ab)</td>
<td>21.11a</td>
<td>-23.94b</td>
<td>-25.89</td>
<td>-26.11</td>
<td>-28.56</td>
<td>-30.17</td>
</tr>
<tr>
<td>24.4 kg N ha⁻¹</td>
<td>(32.50b)</td>
<td>21.11a</td>
<td>-25.00c</td>
<td>-26.44</td>
<td>-26.22</td>
<td>-28.94</td>
<td>-20.22</td>
</tr>
<tr>
<td>Fertilizing frequency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 time/month</td>
<td>(30.83a)</td>
<td>-20.83a</td>
<td>-22.33</td>
<td>-24.29</td>
<td>-24.08</td>
<td>-26.88</td>
<td>-28.17</td>
</tr>
<tr>
<td>2 times/month</td>
<td>(31.25a)</td>
<td>-22.08</td>
<td>-23.88</td>
<td>-25.46</td>
<td>-26.33</td>
<td>-27.63</td>
<td>-29.67</td>
</tr>
</tbody>
</table>

ANOVA results

| Methiozolin    | (0.8845) | 0.2254 | 0.1170 | 0.1060 | 0.0963 | 0.1583  | 0.1630  |
| Nitrogen rates | (0.1911) | 0.8561 | 0.0023 | 0.0621 | 0.3282 | 0.0295  | 0.0959  |
| Fertilizing Frequency | (0.8713) | 0.5537 | 0.2768 | 0.5431 | 0.2785 | 0.5582  | 0.4499  |
| M*N            | (0.3490) | 0.4859 | 0.1241 | 0.2112 | 0.6132 | 0.8114  | 0.8967  |
| M*F            | (0.6137) | 0.3664 | 0.9302 | 0.5431 | 0.6982 | 0.2883  | 0.6608  |
| N*F            | (0.0972) | 0.4753 | 0.7928 | 0.8011 | 0.9121 | 0.6306  | 0.6096  |
| M*N*F          | (0.4582) | 0.0391 | 0.0076 | 0.0525 | 0.2249 | 0.0809  | 0.1228  |

† Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.

‡ For the ANOVA test, block*methiozolin interaction was used as the error term for the main-plot and M*N*block + M*F*block + N*F*block + M*N*F*block interaction was used as the error term for the split-plot.
Table 2.11. Changes of percent coverage visual assessment of voids influenced by methiozolin, nitrogen rates and fertilizing frequency on annual bluegrass control on golf greens after fall treatment, 2015.

<table>
<thead>
<tr>
<th></th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 WAIT</td>
</tr>
<tr>
<td>Methiozolin</td>
<td></td>
</tr>
<tr>
<td>0 kg a.i. ha⁻¹</td>
<td>(15.00a)</td>
</tr>
<tr>
<td>0.53 kg a.i. ha⁻¹</td>
<td>(14.86a)</td>
</tr>
<tr>
<td>Nitrogen rates</td>
<td></td>
</tr>
<tr>
<td>0 kg N ha⁻¹</td>
<td>(15.83a)</td>
</tr>
<tr>
<td>6.1 kg N ha⁻¹</td>
<td>(15.00a)</td>
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<tr>
<td>12.2 kg N ha⁻¹</td>
<td>(14.17a)</td>
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<tr>
<td>24.4 kg N ha⁻¹</td>
<td>(14.72a)</td>
</tr>
<tr>
<td>Fertilizing frequency</td>
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</tr>
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<td>1 time/month</td>
<td>(16.04a)</td>
</tr>
<tr>
<td>2 times/month</td>
<td>(14.38a)</td>
</tr>
<tr>
<td>4 times/month</td>
<td>(14.38a)</td>
</tr>
</tbody>
</table>

ANOVA results ‡

<p>| | | | | | | | |</p>
<table>
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<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
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<td>0.4970</td>
<td>0.5077</td>
<td>0.6427</td>
<td>0.7646</td>
<td>0.8727</td>
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<td>0.6780</td>
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<tr>
<td>Fertilizing Frequency</td>
<td>(0.2514)</td>
<td>0.1418</td>
<td>0.1890</td>
<td>0.0809</td>
<td>0.0970</td>
<td>0.2243</td>
<td>0.1688</td>
</tr>
<tr>
<td>M*N</td>
<td>(0.6464)</td>
<td>0.3892</td>
<td>0.7704</td>
<td>0.8841</td>
<td>0.8342</td>
<td>0.7644</td>
<td>0.7191</td>
</tr>
<tr>
<td>M*F</td>
<td>(0.7023)</td>
<td>0.5457</td>
<td>0.9458</td>
<td>0.5864</td>
<td>0.6451</td>
<td>0.9325</td>
<td>0.7348</td>
</tr>
<tr>
<td>N*F</td>
<td>(0.1251)</td>
<td>0.0420</td>
<td>0.0553</td>
<td>0.0338</td>
<td>0.0639</td>
<td>0.0312</td>
<td>0.1408</td>
</tr>
<tr>
<td>M<em>N</em>F</td>
<td>(0.2267)</td>
<td>0.8070</td>
<td>0.6574</td>
<td>0.4078</td>
<td>0.2676</td>
<td>0.1659</td>
<td>0.2796</td>
</tr>
</tbody>
</table>

† Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
‡ For the ANOVA test, block*methiozolin interaction was used as the error term for the main-plot and M*N*block + M*F*block + N*F*block + M*N*F*block interaction was used as the error term for the split-plot.
Table 2.12. Changes of grid counting percent voids coverage influenced by methiozolin, nitrogen rates and fertilizing frequency on annual bluegrass control on golf greens after fall treatment, 2014.

<table>
<thead>
<tr>
<th></th>
<th>Dates</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(0 WAIT)</td>
<td>4 WAIT</td>
<td>8 WAIT</td>
<td>12 WAIT</td>
</tr>
<tr>
<td>Methiozolin</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 kg a.i. ha⁻¹</td>
<td>(17.70a)</td>
<td>-12.42a †</td>
<td>-15.50a</td>
<td>-17.61a</td>
</tr>
<tr>
<td>0.53 kg a.i. ha⁻¹</td>
<td>(20.98a)</td>
<td>-8.29a</td>
<td>-9.76a</td>
<td>-19.12a</td>
</tr>
<tr>
<td>Nitrogen rates</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 kg N ha⁻¹</td>
<td>(19.24ab)</td>
<td>-10.06ab</td>
<td>-16.44a</td>
<td>-18.92a</td>
</tr>
<tr>
<td>6.1 kg N ha⁻¹</td>
<td>(22.22a)</td>
<td>-13.45a</td>
<td>-15.79a</td>
<td>-21.49a</td>
</tr>
<tr>
<td>12.2 kg N ha⁻¹</td>
<td>(19.70ab)</td>
<td>-11.02a</td>
<td>-12.21a</td>
<td>-18.64a</td>
</tr>
<tr>
<td>24.4 kg N ha⁻¹</td>
<td>(16.21b)</td>
<td>-6.89b</td>
<td>-6.06b</td>
<td>-14.42b</td>
</tr>
<tr>
<td>Fertilizing frequency</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 time/month</td>
<td>(20.25a)</td>
<td>-11.88a</td>
<td>-15.53a</td>
<td>-19.59a</td>
</tr>
<tr>
<td>2 times/month</td>
<td>(19.39a)</td>
<td>-9.47a</td>
<td>-12.09ab</td>
<td>-18.46a</td>
</tr>
<tr>
<td>4 times/month</td>
<td>(18.39a)</td>
<td>-9.71a</td>
<td>-10.26b</td>
<td>-17.05a</td>
</tr>
</tbody>
</table>

ANOVA results‡

<table>
<thead>
<tr>
<th></th>
<th>(0.1326)</th>
<th>0.0721</th>
<th>0.0644</th>
<th>0.3381</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methiozolin</td>
<td>(0.0430)</td>
<td>0.0169</td>
<td>0.0002</td>
<td>0.0076</td>
</tr>
<tr>
<td>Nitrogen rates</td>
<td>(0.5759)</td>
<td>0.3100</td>
<td>0.0384</td>
<td>0.3282</td>
</tr>
<tr>
<td>Fertilizing Frequency</td>
<td>(0.0028)</td>
<td>0.0053</td>
<td>0.0042</td>
<td>0.0041</td>
</tr>
<tr>
<td>M*N</td>
<td>(0.9109)</td>
<td>0.8118</td>
<td>0.5975</td>
<td>0.9845</td>
</tr>
<tr>
<td>M*F</td>
<td>(0.0769)</td>
<td>0.2840</td>
<td>0.2011</td>
<td>0.0616</td>
</tr>
<tr>
<td>N*F</td>
<td>(&lt;.0001)</td>
<td>0.1171</td>
<td>0.0136</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

† Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.

‡ For the ANOVA test, block*methiozolin interaction was used as the error term for the main-plot and M*N*block + M*F*block + N*F*block + M*N*F*block interaction was used as the error term for the split-plot.
Table 2.13. Changes of grid counting percent voids coverage influenced by methiozolin, nitrogen rates and fertilizing frequency on annual bluegrass control on golf greens after fall treatment, 2015.

<table>
<thead>
<tr>
<th>Dates</th>
<th>Methiozolin 0 kg a.i. ha(^{-1})</th>
<th>Methiozolin 0.53 kg a.i. ha(^{-1})</th>
<th>Nitrogen rates 0 kg N ha(^{-1})</th>
<th>Nitrogen rates 6.1 kg N ha(^{-1})</th>
<th>Nitrogen rates 12.2 kg N ha(^{-1})</th>
<th>Nitrogen rates 24.4 kg N ha(^{-1})</th>
<th>Fertilizing frequency 1 time/month</th>
<th>Fertilizing frequency 2 times/month</th>
<th>Fertilizing frequency 4 times/month</th>
</tr>
</thead>
<tbody>
<tr>
<td>(0 WAIT)</td>
<td>(13.57a)</td>
<td>(14.14a)</td>
<td>(13.18a)</td>
<td>(15.24a)</td>
<td>(13.27a)</td>
<td>(13.73a)</td>
<td>(14.15a)</td>
<td>(14.60a)</td>
<td>(12.81a)</td>
</tr>
<tr>
<td>4 WAIT</td>
<td>-11.16(^+)</td>
<td>-11.30a</td>
<td>-10.01a</td>
<td>-12.54a</td>
<td>-10.93a</td>
<td>-11.43a</td>
<td>-11.61a</td>
<td>-11.54a</td>
<td>-10.54a</td>
</tr>
<tr>
<td>8 WAIT</td>
<td>-13.18a</td>
<td>-13.43a</td>
<td>-12.35a</td>
<td>-14.51a</td>
<td>-12.90a</td>
<td>-13.45a</td>
<td>-13.47a</td>
<td>-13.95a</td>
<td>-12.50a</td>
</tr>
<tr>
<td>12 WAIT</td>
<td>-13.45a</td>
<td>-13.89a</td>
<td>-12.86a</td>
<td>-15.06a</td>
<td>-13.13a</td>
<td>-13.64a</td>
<td>-14.02a</td>
<td>-14.29a</td>
<td>-12.71a</td>
</tr>
</tbody>
</table>

ANOVA results\(^\ddagger\):

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Mean Square</th>
<th>F</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methiozolin</td>
<td>(0.7038)</td>
<td>0.8997</td>
<td>0.8395</td>
</tr>
<tr>
<td>Nitrogen rates</td>
<td>(0.7248)</td>
<td>0.5038</td>
<td>0.7088</td>
</tr>
<tr>
<td>Fertilizing Frequency</td>
<td>(0.5766)</td>
<td>0.7127</td>
<td>0.6751</td>
</tr>
<tr>
<td>M*N</td>
<td>(0.1705)</td>
<td>0.2093</td>
<td>0.1361</td>
</tr>
<tr>
<td>M*F</td>
<td>(0.9968)</td>
<td>0.9855</td>
<td>0.9921</td>
</tr>
<tr>
<td>N*F</td>
<td>(0.7472)</td>
<td>0.5900</td>
<td>0.5843</td>
</tr>
<tr>
<td>M<em>N</em>F</td>
<td>(0.1121)</td>
<td>0.2510</td>
<td>0.1206</td>
</tr>
</tbody>
</table>

\(^+\) Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.

\(^\ddagger\) For the ANOVA test, block*methiozolin interaction was used as the error term for the main-plot and M*N*block + M*F*block + N*F*block + M*N*F*block interaction was used as the error term for the split-plot.
### Table 2.14. Visual assessment of annual bluegrass population influenced by methiozolin, nitrogen rates and fertilizing frequency on annual bluegrass control on golf greens after fall treatment, 2014.

<table>
<thead>
<tr>
<th></th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 WAIT</td>
</tr>
<tr>
<td><strong>Methiozolin</strong></td>
<td></td>
</tr>
<tr>
<td>0 kg a.i. ha⁻¹</td>
<td>13.06%a†</td>
</tr>
<tr>
<td>0.53 kg a.i. ha⁻¹</td>
<td>11.11%a</td>
</tr>
<tr>
<td><strong>Nitrogen rates</strong></td>
<td></td>
</tr>
<tr>
<td>0 kg N ha⁻¹</td>
<td>11.50%a</td>
</tr>
<tr>
<td>6.1 kg N ha⁻¹</td>
<td>11.88%a</td>
</tr>
<tr>
<td>12.2 kg N ha⁻¹</td>
<td>12.50%a</td>
</tr>
<tr>
<td>24.4 kg N ha⁻¹</td>
<td>12.50%a</td>
</tr>
<tr>
<td><strong>Fertilizing frequency</strong></td>
<td></td>
</tr>
<tr>
<td>1 time/month</td>
<td>12.08%a</td>
</tr>
<tr>
<td>2 times/month</td>
<td>12.50%a</td>
</tr>
<tr>
<td>4 times/month</td>
<td>11.67%a</td>
</tr>
<tr>
<td><strong>ANOVA results</strong></td>
<td></td>
</tr>
<tr>
<td>Methiozolin</td>
<td>0.2126</td>
</tr>
<tr>
<td>Nitrogen rates</td>
<td>0.7796</td>
</tr>
<tr>
<td>Fertilizing Frequency</td>
<td>0.9686</td>
</tr>
<tr>
<td>M*N</td>
<td>0.6010</td>
</tr>
<tr>
<td>M*F</td>
<td>0.8029</td>
</tr>
<tr>
<td>N*F</td>
<td>0.9230</td>
</tr>
<tr>
<td>M<em>N</em>F</td>
<td>0.9354</td>
</tr>
</tbody>
</table>

† Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.

‡ For the ANOVA test, block*methiozolin interaction was used as the error term for the main-plot and M*N*block + M*F*block + N*F*block + M*N*F*block interaction was used as the error term for the split-plot.
Table 2.15. Visual assessment of annual bluegrass population influenced by methiozolin, nitrogen rates and fertilizing frequency on annual bluegrass control on golf greens after fall treatment, 2015.

<table>
<thead>
<tr>
<th></th>
<th>Dates</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 WAIT</td>
<td>2 WAIT</td>
<td>4 WAIT</td>
<td>6 WAIT</td>
<td>8 WAIT</td>
<td>10 WAIT</td>
<td>12 WAIT</td>
</tr>
<tr>
<td>Methiozolin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 kg a.i. ha⁻¹</td>
<td>4.92%a†</td>
<td>5.11%a</td>
<td>4.64%a</td>
<td>3.56%a</td>
<td>4.42%a</td>
<td>5.83%a</td>
<td>5.56%a</td>
</tr>
<tr>
<td>0.53 kg a.i. ha⁻¹</td>
<td>5.14%a</td>
<td>5.17%a</td>
<td>4.28%a</td>
<td>1.97%a</td>
<td>2.44%a</td>
<td>2.58%a</td>
<td>2.31%b</td>
</tr>
<tr>
<td>Nitrogen rates</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 kg N ha⁻¹</td>
<td>4.38%a</td>
<td>8.83%a</td>
<td>7.83%a</td>
<td>4.56%a</td>
<td>5.33%a</td>
<td>6.33%a</td>
<td>4.89%a</td>
</tr>
<tr>
<td>6.1 kg N ha⁻¹</td>
<td>4.89%a</td>
<td>4.00%b</td>
<td>4.44%b</td>
<td>3.56%ab</td>
<td>4.00%ab</td>
<td>4.50%ab</td>
<td>3.33%ab</td>
</tr>
<tr>
<td>12.2 kg N ha⁻¹</td>
<td>5.17%a</td>
<td>4.22%b</td>
<td>2.61%b</td>
<td>1.17%c</td>
<td>2.17%b</td>
<td>2.72%b</td>
<td>2.50%b</td>
</tr>
<tr>
<td>24.4 kg N ha⁻¹</td>
<td>5.78%a</td>
<td>3.50%b</td>
<td>2.94%b</td>
<td>1.78%bc</td>
<td>2.22%b</td>
<td>3.28%b</td>
<td>5.00%a</td>
</tr>
<tr>
<td>Fertilizing frequency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 time/month</td>
<td>5.33%a</td>
<td>6.17%a</td>
<td>6.75%a</td>
<td>3.63%a</td>
<td>5.38%a</td>
<td>5.71%a</td>
<td>4.53%a</td>
</tr>
<tr>
<td>2 times/month</td>
<td>4.63%a</td>
<td>2.25%ab</td>
<td>3.75%b</td>
<td>2.71%a</td>
<td>2.92%b</td>
<td>3.67%ab</td>
<td>3.25%a</td>
</tr>
<tr>
<td>4 times/month</td>
<td>5.13%a</td>
<td>4.00%b</td>
<td>2.88%b</td>
<td>1.96%a</td>
<td>2.00%b</td>
<td>3.25%b</td>
<td>3.92%a</td>
</tr>
</tbody>
</table>

ANOVA results

<table>
<thead>
<tr>
<th></th>
<th>M*F</th>
<th>N*F</th>
<th>M<em>N</em>F*F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methiozolin</td>
<td>0.5949</td>
<td>0.0229</td>
<td>0.0309</td>
</tr>
<tr>
<td>Nitrogen rates</td>
<td>0.3866</td>
<td>0.0017</td>
<td>0.0102</td>
</tr>
<tr>
<td>Fertilizing Frequency</td>
<td>0.6273</td>
<td>0.0594</td>
<td>0.3997</td>
</tr>
<tr>
<td>M*N</td>
<td>0.1864</td>
<td>0.0276</td>
<td>0.00276</td>
</tr>
<tr>
<td>M<em>F</em>block</td>
<td>0.4378</td>
<td>0.6366</td>
<td>0.8630</td>
</tr>
<tr>
<td>N<em>F</em>block</td>
<td>0.3904</td>
<td>0.325a</td>
<td>0.4314</td>
</tr>
<tr>
<td>M<em>N</em>F*block</td>
<td>0.3551</td>
<td>0.5408</td>
<td>0.6692</td>
</tr>
</tbody>
</table>

† Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
‡ For the ANOVA test, block*methiozolin interaction was used as the error term for the main-plot and M*N*block + M*F*block + N*F*block + M*N*F*block interaction was used as the error term for the split-plot.
Table 2.16. Grid counting of annual bluegrass population influenced by methiozolin, nitrogen rates and fertilizing frequency on annual bluegrass control on golf greens after fall treatment, 2014.

<table>
<thead>
<tr>
<th></th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4 WAIT</td>
</tr>
<tr>
<td><strong>Methiozolin</strong></td>
<td></td>
</tr>
<tr>
<td>0 kg a.i. ha(^{-1})</td>
<td>6.54%a</td>
</tr>
<tr>
<td>0.53 kg a.i. ha(^{-1})</td>
<td>2.76%a</td>
</tr>
<tr>
<td><strong>Nitrogen rates</strong></td>
<td></td>
</tr>
<tr>
<td>0 kg N ha(^{-1})</td>
<td>5.97%a</td>
</tr>
<tr>
<td>6.1 kg N ha(^{-1})</td>
<td>4.64%a</td>
</tr>
<tr>
<td>12.2 kg N ha(^{-1})</td>
<td>4.27%a</td>
</tr>
<tr>
<td>24.4 kg N ha(^{-1})</td>
<td>3.72%a</td>
</tr>
<tr>
<td><strong>Fertilizing frequency</strong></td>
<td></td>
</tr>
<tr>
<td>1 time/month</td>
<td>4.24%ab</td>
</tr>
<tr>
<td>2 times/month</td>
<td>6.06%a</td>
</tr>
<tr>
<td>4 times/month</td>
<td>3.65%a</td>
</tr>
<tr>
<td><strong>ANOVA results</strong></td>
<td></td>
</tr>
<tr>
<td>Methiozolin</td>
<td>0.1404</td>
</tr>
<tr>
<td>Nitrogen rates</td>
<td>0.3073</td>
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<td>Fertilizing Frequency</td>
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</tr>
<tr>
<td>M*N</td>
<td>0.4085</td>
</tr>
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<td>M*F</td>
<td>0.5936</td>
</tr>
<tr>
<td>N*F</td>
<td>0.9213</td>
</tr>
<tr>
<td>M<em>N</em>F</td>
<td>0.8659</td>
</tr>
</tbody>
</table>

† Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.

‡ For the ANOVA test, block*methiozolin interaction was used as the error term for the main-plot and M*N*block + M*F*block + N*F*block + M*N*F*block interaction was used as the error term for the split-plot.
Table 2.17. Changes of grid counting of annual bluegrass population influenced by methiozolin, nitrogen rates and fertilizing frequency on annual bluegrass control on golf greens after fall treatment, 2015.

<table>
<thead>
<tr>
<th></th>
<th>Dates</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 WAIT</td>
<td>4 WAIT</td>
<td>8 WAIT</td>
<td>12 WAIT</td>
</tr>
<tr>
<td>Methiozolin</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 kg a.i. ha⁻¹</td>
<td>4.50%a†</td>
<td>4.20%a</td>
<td>2.39%a</td>
<td>2.87%a</td>
</tr>
<tr>
<td>0.53 kg a.i. ha⁻¹</td>
<td>4.32%a</td>
<td>3.47%a</td>
<td>2.02%a</td>
<td>1.33%a</td>
</tr>
<tr>
<td>Nitrogen rates</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 kg N ha⁻¹</td>
<td>4.59%a</td>
<td>4.64%a</td>
<td>2.43%a</td>
<td>2.34%ab</td>
</tr>
<tr>
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<td>2 times/month</td>
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ANOVA results⁵

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† Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.

‡ For the ANOVA test, block*methiozolin interaction was used as the error term for the main-plot and M*N*block + M*F*block + N*F*block + M*N*F*block interaction was used as the error term for the split-plot.
Figure 2.1. The effect of spring Methiozolin on NDVI of creeping bentgrass showing the creeping bentgrass color quality 0, 2, 4, 6, 8, 10, and 12 weeks after initial treatment in 2014 and 2015.

* indicates significant difference at level of P ≤ 0.05.

^ indicates the dates when methiozolin treatments were applied.
Figure 2.2. The effects of nitrogen rates on the NDVI of creeping bentgrass when applied a) once per month, b) twice per month, and c) four times per month two weeks after the initial treatment in 2014 and 2015.

$N_0 = 0$ kg N ha$^{-1}$, $N_1 = 6.1$ kg N ha$^{-1}$, $N_2 = 12.2$ kg N ha$^{-1}$, $N_4 = 24.4$ kg N ha$^{-1}$.

$^1$ One application had been done for once per month and twice per month frequencies, and two applications had been done for four times per month frequency.
Figure 2.3. The effects of nitrogen rates on the NDVI of creeping bentgrass when applied a) once per month, b) twice per month, and c) four times per month four weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha\(^{-1}\), N1 = 6.1 kg N ha\(^{-1}\), N2 = 12.2 kg N ha\(^{-1}\), N4 = 24.4 kg N ha\(^{-1}\).

2 One application had been done for once per month frequency, two applications had been done for twice per month frequencies, and three applications had been done for four times per month frequency.
Figure 2.4. The effects of nitrogen rates on the NDVI of creeping bentgrass when applied a) once per month, b) twice per month, and c) four times per month six weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha\(^{-1}\), N1 = 6.1 kg N ha\(^{-1}\), N2 = 12.2 kg N ha\(^{-1}\), N4 = 24.4 kg N ha\(^{-1}\).
2 Two applications had been done for once per month frequency, three applications had been done for twice per month frequencies, and six applications had been done for four times per month frequency.
Figure 2.5. The effects of nitrogen rates on the NDVI of creeping bentgrass when applied a) once per month, b) twice per month, and c) four times per month eight weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha\(^{-1}\), N1 = 6.1 kg N ha\(^{-1}\), N2 = 12.2 kg N ha\(^{-1}\), N4 = 24.4 kg N ha\(^{-1}\).

2 Two applications had been done for once per month frequency, four applications had been done for twice per month frequency, and eight applications had been done for four times per month frequency.

3 Four weeks after the last application for once per month frequency, two weeks after the last application for twice per month frequency, and one week after the last application for four times per month frequency.
Figure 2.6. The effects of nitrogen rates on the NDVI of creeping bentgrass when applied a) once per month, b) twice per month, and c) four times per month ten weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha⁻¹, N1 = 6.1 kg N ha⁻¹, N2 = 12.2 kg N ha⁻¹, N4 = 24.4 kg N ha⁻¹.
2 Six weeks after the last application for once per month frequency, four weeks after the last application for twice per month frequency, and three weeks after the last application for four times per month frequency.
Figure 2.7. The effects of nitrogen rates on the NDVI of creeping bentgrass when applied a) once per month, b) twice per month, and c) four times per month twelve weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha\(^{-1}\), N1 = 6.1 kg N ha\(^{-1}\), N2 = 12.2 kg N ha\(^{-1}\), N4 = 24.4 kg N ha\(^{-1}\).

2 Eight weeks after the last application for once per month frequency, six weeks after the last application for twice per month frequency, and five weeks after the last application for four times per month frequency.
Figure 2.8. The effect of spring Methiozolin on Green Index of creeping bentgrass showing the creeping bentgrass color quality 0, 2, 4, 6, 8, 10, and 12 weeks after initial treatment in 2014 and 2015.

* indicates significant difference at level of $P \leq 0.05$.
^ indicates the dates when methiozolin treatments were applied.
Figure 2.9. The effects of nitrogen rates on the Green Index of creeping bentgrass when applied a) once per month, b) twice per month, and c) four times per month two weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha\(^{-1}\), N1 = 6.1 kg N ha\(^{-1}\), N2 = 12.2 kg N ha\(^{-1}\), N4 = 24.4 kg N ha\(^{-1}\).
2 One application had been done for once per month and twice per month frequencies, and two applications had been done for four times per month frequency.
Figure 2.10. The effects of nitrogen rates on the Green Index of creeping bentgrass when applied a) once per month, b) twice per month, and c) four times per month four weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha\(^{-1}\), N1 = 6.1 kg N ha\(^{-1}\), N2 = 12.2 kg N ha\(^{-1}\), N4 = 24.4 kg N ha\(^{-1}\).

2 One application had been done for once per month frequency, two applications had been done for twice per month frequency, and three applications had been done for four times per month frequency.
Figure 2.11. The effects of nitrogen rates on the Green Index of creeping bentgrass when applied a) once per month, b) twice per month, and c) four times per month six weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha\(^{-1}\), N1 = 6.1 kg N ha\(^{-1}\), N2 = 12.2 kg N ha\(^{-1}\), N4 = 24.4 kg N ha\(^{-1}\).

2 Two applications had been done for once per month frequency, three applications had been done for twice per month frequency, and six applications had been done for four times per month frequency.
Figure 2.12. The effects of nitrogen rates on the Green Index of creeping bentgrass when applied a) once per month, b) twice per month, and c) four times per month eight weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha$^{-1}$, N1 = 6.1 kg N ha$^{-1}$, N2 = 12.2 kg N ha$^{-1}$, N4 = 24.4 kg N ha$^{-1}$.

2 Two applications had been done for once per month frequency, four applications had been done for twice per month frequency, and eight applications had been done for four times per month frequency.

3 Four weeks after the last application for once per month frequency, two weeks after the last application for twice per month frequency, and one week after the last application for four times per month frequency.
Figure 2.13. The effects of nitrogen rates on the Green Index of creeping bentgrass when applied a) once per month, b) twice per month, and c) four times per month ten weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha\(^{-1}\), N1 = 6.1 kg N ha\(^{-1}\), N2 = 12.2 kg N ha\(^{-1}\), N4 = 24.4 kg N ha\(^{-1}\).

2 Six weeks after the last application for once per month frequency, four weeks after the last application for twice per month frequency, and three weeks after the last application for four times per month frequency.
Figure 2.14. The effects of nitrogen rates on the Green Index of creeping bentgrass when applied a) once per month, b) twice per month, and c) four times per month twelve weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha\(^{-1}\), N1 = 6.1 kg N ha\(^{-1}\), N2 = 12.2 kg N ha\(^{-1}\), N4 = 24.4 kg N ha\(^{-1}\).
2 Eight weeks after the last application for once per month frequency, six weeks after the last application for twice per month frequency, and five weeks after the last application for four times per month frequency.
Figure 2.15. The effect of spring Methiozolin on visual assessment of creeping bentgrass color 0, 2, 4, 6, 8, 10, and 12 weeks after initial treatment in 2014 and 2015.

* indicates significant difference at level of $P \leq 0.05$.

^ indicates the dates when methiozolin treatments were applied.
Figure 2.16. The effects of nitrogen rates on visual assessment of creeping bentgrass color when applied a) once per month, b) twice per month, and c) four times per month two weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha\(^{-1}\), N1 = 6.1 kg N ha\(^{-1}\), N2 = 12.2 kg N ha\(^{-1}\), N4 = 24.4 kg N ha\(^{-1}\).

2 One application had been done for once per month and twice per month frequencies, and two applications had been done for four times per month frequency.
Figure 2.17. The effects of nitrogen rates on visual assessment of creeping bentgrass color when applied a) once per month, b) twice per month, and c) four times per month four weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha⁻¹, N1 = 6.1 kg N ha⁻¹, N2 = 12.2 kg N ha⁻¹, N4 = 24.4 kg N ha⁻¹.
2 One application had been done for once per month frequency, two applications had been done for twice per month frequencies, and three applications had been done for four times per month frequency.
Figure 2.18. The effects of nitrogen rates on visual assessment of creeping bentgrass color when applied a) once per month, b) twice per month, and c) four times per month six weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha\(^{-1}\), N1 = 6.1 kg N ha\(^{-1}\), N2 = 12.2 kg N ha\(^{-1}\), N4 = 24.4 kg N ha\(^{-1}\).
2 Two applications had been done for once per month frequency, three applications had been done for twice per month frequencies, and six applications had been done for four times per month frequency.
Figure 2.19. The effects of nitrogen rates on visual assessment of creeping bentgrass color when applied a) once per month, b) twice per month, and c) four times per month eight weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha\(^{-1}\), N1 = 6.1 kg N ha\(^{-1}\), N2 = 12.2 kg N ha\(^{-1}\), N4 = 24.4 kg N ha\(^{-1}\).

2 Two applications had been done for once per month frequency, four applications had been done for twice per month frequency, and eight applications had been done for four times per month frequency.

3 Four weeks after the last application for once per month frequency, two weeks after the last application for twice per month frequency, and one week after the last application for four times per month frequency.
Figure 2.20. The effects of nitrogen rates on visual assessment of creeping bentgrass color when applied a) once per month, b) twice per month, and c) four times per month ten weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha⁻¹, N1 = 6.1 kg N ha⁻¹, N2 = 12.2 kg N ha⁻¹, N4 = 24.4 kg N ha⁻¹.
2 Six weeks after the last application for once per month frequency, four weeks after the last application for twice per month frequency, and three weeks after the last application for four times per month frequency.
Figure 2.21. The effects of nitrogen rates on visual assessment of creeping bentgrass color when applied a) once per month, b) twice per month, and c) four times per month twelve weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha⁻¹, N1 = 6.1 kg N ha⁻¹, N2 = 12.2 kg N ha⁻¹, N4 = 24.4 kg N ha⁻¹.
2 Eight weeks after the last application for once per month frequency, six weeks after the last application for twice per month frequency, and five weeks after the last application for four times per month frequency.
Figure 2.22. The effect of spring Methiozolin on the changes of visual assessment percent voids coverage 2, 4, 6, 8, 10, and 12 weeks after initial treatment in 2014 and 2015.

* indicates significant difference at level of $P \leq 0.05$.

^ indicates the dates when methiozolin treatments were applied.
Figure 2.23. The effects of nitrogen rates on the changes of visual assessment percent voids coverage when applied a) once per month, b) twice per month, and c) four times per month two weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha⁻¹, N1 = 6.1 kg N ha⁻¹, N2 = 12.2 kg N ha⁻¹, N4 = 24.4 kg N ha⁻¹.
2 One application had been done for once per month and twice per month frequencies, and two applications had been done for four times per month frequency.
Figure 2.24. The effects of nitrogen rates on the changes of visual assessment percent voids coverage when applied a) once per month, b) twice per month, and c) four times per month four weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha⁻¹, N1 = 6.1 kg N ha⁻¹, N2 = 12.2 kg N ha⁻¹, N4 = 24.4 kg N ha⁻¹.
2 One application had been done for once per month frequency, two applications had been done for twice per month frequency, and three applications had been done for four times per month frequency.
Figure 2.2. The effects of nitrogen rates on the changes of visual assessment percent voids coverage when applied a) once per month, b) twice per month, and c) four times per month six weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha\(^{-1}\), N1 = 6.1 kg N ha\(^{-1}\), N2 = 12.2 kg N ha\(^{-1}\), N4 = 24.4 kg N ha\(^{-1}\).

2 Two applications had been done for once per month frequency, three applications had been done for twice per month frequency, and six applications had been done for four times per month frequency.
Figure 2.26. The effects of nitrogen rates on the changes of visual assessment percent voids coverage when applied a) once per month, b) twice per month, and c) four times per month eight weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha⁻¹, N1 = 6.1 kg N ha⁻¹, N2 = 12.2 kg N ha⁻¹, N4 = 24.4 kg N ha⁻¹.
2 Two applications had been done for once per month frequency, four applications had been done for twice per month frequency, and eight applications had been done for four times per month frequency.
3 Four weeks after the last application for once per month frequency, two weeks after the last application for twice per month frequency, and one week after the last application for four times per month frequency.
Figure 2.27. The effects of nitrogen rates on the changes of visual assessment percent voids coverage when applied a) once per month, b) twice per month, and c) four times per month ten weeks after the initial treatment in 2014 and 2015.

1 $N_0 = 0 \text{ kg N ha}^{-1}$, $N_1 = 6.1 \text{ kg N ha}^{-1}$, $N_2 = 12.2 \text{ kg N ha}^{-1}$, $N_4 = 24.4 \text{ kg N ha}^{-1}$.

2 Six weeks after the last application for once per month frequency, four weeks after the last application for twice per month frequency, and three weeks after the last application for four times per month frequency.
Figure 2.28. The effects of nitrogen rates on the changes of visual assessment percent voids coverage when applied a) once per month, b) twice per month, and c) four times per month twelve weeks after the initial treatment in 2014 and 2015.

1 \( N_0 = 0 \text{ kg N ha}^{-1}, N_1 = 6.1 \text{ kg N ha}^{-1}, N_2 = 12.2 \text{ kg N ha}^{-1}, N_4 = 24.4 \text{ kg N ha}^{-1} \).

2 Eight weeks after the last application for once per month frequency, six weeks after the last application for twice per month frequency, and five weeks after the last application for four times per month frequency.
Figure 2.29. The effect of spring Methiozolin on the changes of grid counting percent voids coverage 4, 8, and 12 weeks after initial treatment in 2014 and 2015.

* indicates significant difference at level of $P \leq 0.05$. 
Figure 2.30. The effects of nitrogen rates on the changes of grid counting percent voids coverage when applied a) once per month, b) twice per month, and c) four times per month four weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha\(^{-1}\), N1 = 6.1 kg N ha\(^{-1}\), N2 = 12.2 kg N ha\(^{-1}\), N4 = 24.4 kg N ha\(^{-1}\).

2 One application had been done for once per month frequency, two applications had been done for twice per month frequency, and three applications had been done for four times per month frequency.
Figure 2.31. The effects of nitrogen rates on the changes of grid counting percent voids coverage when applied a) once per month, b) twice per month, and c) four times per month eight weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha\(^{-1}\), N1 = 6.1 kg N ha\(^{-1}\), N2 = 12.2 kg N ha\(^{-1}\), N4 = 24.4 kg N ha\(^{-1}\).
2 Two applications had been done for once per month frequency, four applications had been done for twice per month frequency, and eight applications had been done for four times per month frequency.
3 Four weeks after the last application for once per month frequency, two weeks after the last application for twice per month frequency, and one week after the last application for four times per month frequency.
Figure 2.3. The effects of nitrogen rates on the changes of grid counting percent voids coverage when applied a) once per month, b) twice per month, and c) four times per month twelve weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha\(^{-1}\), N1 = 6.1 kg N ha\(^{-1}\), N2 = 12.2 kg N ha\(^{-1}\), N4 = 24.4 kg N ha\(^{-1}\).

2 Eight weeks after the last application for once per month frequency, six weeks after the last application for twice per month frequency, and five weeks after the last application for four times per month frequency.
Figure 2.33. The effect of spring Methiozolin on the visual assessment of annual bluegrass population 2, 4, 6, 8, 10, and 12 weeks after initial treatment in 2014 and 2015.

* indicates significant difference at level of $P \leq 0.05$.

^ indicates the dates when methiozolin treatments were applied.
Figure 2.3. The effects of nitrogen rates on the visual assessment of annual bluegrass population when applied a) once per month, b) twice per month, and c) four times per month two weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha\(^{-1}\), N1 = 6.1 kg N ha\(^{-1}\), N2 = 12.2 kg N ha\(^{-1}\), N4 = 24.4 kg N ha\(^{-1}\).

2 One application had been done for once per month and twice per month frequencies, and two applications had been done for four times per month frequency.
Figure 2.35. The effects of nitrogen rates on the visual assessment of annual bluegrass population when applied a) once per month, b) twice per month, and c) four times per month four weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha\(^{-1}\), N1 = 6.1 kg N ha\(^{-1}\), N2 = 12.2 kg N ha\(^{-1}\), N4 = 24.4 kg N ha\(^{-1}\).

2 One application had been done for once per month frequency, two applications had been done for twice per month frequency, and three applications had been done for four times per month frequency.
Figure 2.36. The effects of nitrogen rates on the visual assessment of annual bluegrass population when applied a) once per month, b) twice per month, and c) four times per month six weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha⁻¹, N1 = 6.1 kg N ha⁻¹, N2 = 12.2 kg N ha⁻¹, N4 = 24.4 kg N ha⁻¹.
2 Two applications had been done for once per month frequency, three applications had been done for twice per month frequency, and six applications had been done for four times per month frequency.
Figure 2.37. The effects of nitrogen rates on the visual assessment of annual bluegrass population when applied a) once per month, b) twice per month, and c) four times per month eight weeks after the initial treatment in 2014 and 2015.

1 $N_0 = 0 \text{ kg N ha}^{-1}$, $N_1 = 6.1 \text{ kg N ha}^{-1}$, $N_2 = 12.2 \text{ kg N ha}^{-1}$, $N_4 = 24.4 \text{ kg N ha}^{-1}$.

2 Two applications had been done for once per month frequency, four applications had been done for twice per month frequency, and eight applications had been done for four times per month frequency.

3 Four weeks after the last application for once per month frequency, two weeks after the last application for twice per month frequency, and one week after the last application for four times per month frequency.
Figure 2.38. The effects of nitrogen rates on the visual assessment of annual bluegrass population when applied a) once per month, b) twice per month, and c) four times per month ten weeks after the initial treatment in 2014 and 2015.

\[ N_0 = 0 \text{ kg N ha}^{-1}, N_1 = 6.1 \text{ kg N ha}^{-1}, N_2 = 12.2 \text{ kg N ha}^{-1}, N_4 = 24.4 \text{ kg N ha}^{-1}. \]

\[ ^2\text{Six weeks after the last application for once per month frequency, four weeks after the last application for twice per month frequency, and three weeks after the last application for four times per month frequency.} \]
Figure 2.39. The effects of nitrogen rates on the visual assessment of annual bluegrass population when applied a) once per month, b) twice per month, and c) four times per month twelve weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha\(^{-1}\), N1 = 6.1 kg N ha\(^{-1}\), N2 = 12.2 kg N ha\(^{-1}\), N4 = 24.4 kg N ha\(^{-1}\).
2 Eight weeks after the last application for once per month frequency, six weeks after the last application for twice per month frequency, and five weeks after the last application for four times per month frequency.
Figure 2.40. The effect of spring methiozolin on the grid counting annual bluegrass population 4, 8, and 12 weeks after initial treatment in 2014 and 2015.

* indicates significant difference at level of P ≤ 0.05.
Figure 2.41. The effects of nitrogen rates on the grid counting annual bluegrass population when applied a) once per month, b) twice per month, and c) four times per month four weeks after the initial treatment in 2014 and 2015.

\[N_0 = 0 \text{ kg N ha}^{-1}, \ N_1 = 6.1 \text{ kg N ha}^{-1}, \ N_2 = 12.2 \text{ kg N ha}^{-1}, \ N_4 = 24.4 \text{ kg N ha}^{-1}.\]

\[\text{One application had been done for once per month frequency, two applications had been done for twice per month frequency, and three applications had been done for four times per month frequency.}\]
Figure 2.42. The effects of nitrogen rates on the changes of grid counting annual bluegrass population when applied a) once per month, b) twice per month, and c) four times per month eight weeks after the initial treatment in 2014 and 2015.

1 N0 = 0 kg N ha\(^{-1}\), N1 = 6.1 kg N ha\(^{-1}\), N2 = 12.2 kg N ha\(^{-1}\), N4 = 24.4 kg N ha\(^{-1}\).
2 Two applications had been done for once per month frequency, four applications had been done for twice per month frequency, and eight applications had been done for four times per month frequency.
3 Four weeks after the last application for once per month frequency, two weeks after the last application for twice per month frequency, and one week after the last application for four times per month frequency.
Figure 2.43. The effects of nitrogen rates on the changes of grid counting annual bluegrass population when applied a) once per month, b) twice per month, and c) four times per month twelve weeks after the initial treatment in 2014 and 2015.

1 $N_0 = 0 \text{ kg N ha}^{-1}$, $N_1 = 6.1 \text{ kg N ha}^{-1}$, $N_2 = 12.2 \text{ kg N ha}^{-1}$, $N_4 = 24.4 \text{ kg N ha}^{-1}$.

2 Eight weeks after the last application for once per month frequency, six weeks after the last application for twice per month frequency, and five weeks after the last application for four times per month frequency.
Chapter 3: The Effects of Methiozolin and Nitrogen Rates for Spring Annual Bluegrass Control on Creeping Bentgrass Greens

Introduction

Methiozolin has proven to be a more effective post-emergence herbicide on annual bluegrass control when applied in the fall than in the spring (Koo et al., 2013). Even though, spring applications of methiozolin have the advantage of slow conversion from annual bluegrass to creeping bentgrass without leaving obvious voids, it has been widely recognized by researchers and superintendents that spring applications of methiozolin has less control efficiency on the annual bluegrass than fall applications. As a result, there is a need to determine a way to increase the annual bluegrass control efficiency of spring applications of methiozolin without interrupting the playability/quality of the creeping bentgrass putting surface. There are two potential ways to achieve this goal. The first possible way is by increasing the methiozolin rate of each application. The second one is by increasing the total number of applications. Because of the phytotoxicity potential on creeping bentgrass caused by methiozolin under low temperature condition and natural decline of annual bluegrass under high temperature condition, the window suitable for methiozolin applications in the spring is very limited. It is easier to increase the methiozolin rate per application than to increase application times in order to promote annual bluegrass control with spring-applied methiozolin.
Nitrogen, is one of the essential elements of plants. It is the main component of protein and has great influence on the lateral growth and chlorophyll formation of the plant. Nitrogen fertilization has a great influence on the growth rate, color and other quality characteristics of the turfgrass. It may help to encourage creeping bentgrass growth and reduce the chance of phytotoxicity caused by higher methiozolin rates on creeping bentgrass. It may also help creeping bentgrass compete over weakened annual bluegrass after methiozolin treatments and increase the efficiency of methiozolin on annual bluegrass control. By studying the interaction between nitrogen and methiozolin, the best combination of spring methiozolin rate and nitrogen rates which had the most control efficiency on annual bluegrass and least interruption of the playability of the creeping bentgrass putting surface was determined.

The objectives of this project were 1) to determine the effects of spring-applied methiozolin rates and nitrogen rates on the surface quality of creeping bentgrass; 2) to determine the effects of methiozolin rates and nitrogen rates on annual bluegrass suppression/control; and 3) to determine the effects of methiozolin rates and nitrogen rates on the change in the annual bluegrass population by encouraging creeping bentgrass lateral growth.

Material and Methods

A two-year field study was conducted from April, 2014 to July, 2015 on the Scarlet putting green of the Ohio State University Golf Club, located in Columbus, Ohio. The green had been renovated in 2010 to “L-93”creeping bentgrass. After approximately 5 years, there was an existing stand of annual bluegrass averaging 20% coverage
throughout the whole green. According to the soil test, the soil pH on this green was 7.2. The available macronutrient in the soil, including phosphorus, potassium, calcium and magnesium, were 224.17 kg ha\(^{-1}\), 221.93 kg ha\(^{-1}\), 3,511.63 kg ha\(^{-1}\), and 210.72 kg ha\(^{-1}\), respectively. The available micronutrient in the soil, including iron, manganese, zinc and copper, were 63.89 kg ha\(^{-1}\), 6.73 kg ha\(^{-1}\), 16.03 kg ha\(^{-1}\) and 3.92 kg ha\(^{-1}\), respectively. These latter values are well within the sufficiency range considered adequate for creeping bentgrass.

The area was functioning as a practice putting green, and maintained in the same way as the other Scarlett golf greens. The green was mowed daily at the height of 3.2 mm with a walk-behind reel mower. The area was verticut (ThatchAway Techs) on April 14, and topdressed, verticut (Graden AIRROW verticutter) and core aerified with 12.7 mm hollow tine (Toro PROCORE 648) on April 21. No other culture practices with soil disturbance were performed during the study. The whole green was topdressed three times during the growing season on June 17, June 26 and July 7. All the fertilizer and plant growth regulator applications were skipped on the testing area, since nitrogen rate is one of the treatments and methiozolin is considered to have plant growth regulator effects.

For disease control, a total of 38.92 kg a.i. ha\(^{-1}\) of Chlorothalonil (tetrachloroisophthalonitrile) (Daconil Action, Syngenta Crop Protection, Greensboro, NC; Manicure Ultra, Lesco Lab, Cleveland, OH), 0.426 kg a.i. ha\(^{-1}\) of pyraclostrobin (carbamic acid, \([2-[[[1-(4-chlorophenyl)-1H-pyrazol-3-yl]oxy]methyl]phenyl]methoxy\)-methyl ester (Insignia, BASF Corporation, Research Triangle Park, NC) were applied to the area
during the experiment period. Modified alkylated polyol (Revolution, Aquatrols Corp of America, Paulsboro, NJ) was also applied as a wetting agent at the rate of 2.14 kg a.i. ha\(^{-1}\) on July 13.

A 4 × 3 factorial experiment was set up as a random complete block design with three replications. Four levels of methiozolin rate (0, 0.53, 0.80, and 1.06 kg a.i. ha\(^{-1}\)) and three levels of nitrogen rate (6.1, 12.2, and 24.4 kg N ha\(^{-1}\)) were randomized within each block. All the treatments are shown in Table 3.1. The size of the plot was 1.82 by 0.91 m. There was 0.15 m border space between the plots along the long side and 0.3 m border space between the plots along the short side. The whole experiment area was 19.35 by 3.96 m. In the second year (spring 2015), the whole experiment was repeated with the same design and laid out in a new adjacent area on the same putting green. All the treatments were re-randomized in the repeated experiment.

The initial application of spring methiozolin treatments and nitrogen treatments was started on April 26 in 2014 and May 6 in 2015. All the treatments of methiozolin and nitrogen were applied at two-week intervals. The application dates of methiozolin and nitrogen and the daily air temperature on each application day are as listed in Table 3.2. Ammonium sulfate (S‘Sul, American Plant Food Corp., Galena Park, TX) was used as the N-source. All treatments were sprayed with a CO\(_2\) backpack sprayer (300 kPa) equipped with a Tjn_TP6503 (Teejet, Wheaton, IL) flat fan nozzle, which was calibrated to deliver 845.88 L liquid per ha.

Initial baseline data was taken before the first treatment application in each year and all the data was collected every two weeks after the initial treatment (WAIT). The
measurements focused mainly on two aspects: color/quality of the creeping bentgrass and annual bluegrass and the population of annual bluegrass. The measurement methods for turf color/quality include visual assessment, normalized difference vegetation index (NDVI), dark green color index (DGCI) and digital image analysis (DIA). The measurement methods for percent coverage of the annual bluegrass population include visual assessment, grid counting and digital image analysis (DIA).

Visual assessment of creeping bentgrass color/quality was rated according to the NTEP guide for turfgrass color/quality ratings. Creeping bentgrass spring green-up color/quality was rated based on a 1 to 9 scale, with 1 being entirely straw brown; 6 being minimum acceptance of color by a golf course superintendent; and 9 being completely dark green color. The annual bluegrass color/quality was also rated based on a 1 to 9 scale, in which 1 stands for totally brown/dead turf; 6 stands for recognizable yellowing from herbicide treatment; and 9 stands for completely green with annual bluegrass natural genetic color. The visual assessment of the annual bluegrass population was rated according to the living ground cover evaluation from the NTEP Turfgrass Ratings Guide. The coverage assessment expresses the change in the annual bluegrass ground coverage after the methiozolin treatments. The same person took all the visual assessments every two weeks over the two year experimental period.

Normalized difference vegetation index first raised by Rouse et al. (1973) is a function of visible red reflectance (VIS) and near-infrared reflectance (NIR).

\[
NDVI = \frac{(NIR - VIS)}{(NIR + VIS)}
\]
Many scientists have utilized NDVI as a method to evaluate turfgrass canopy characteristics, especially the turfgrass color (Trenholm et al., 1999; Jiang et al., 2003; Xiong et al., 2007; Sönmez et al., 2008). NDVI was taken with a TCM 500 NDVI turf color meter (FieldScout Spectrum Technologies, Inc., Aurora, IL). The NDVI turf color meter has a light chamber with internal light source to negate the interference from external light. The measurement area consisted of a 7.6 cm diameter circular opening on the bottom of the light chamber. Four NDVI samples were randomly taken in each plot for creeping bentgrass and due to the rather small population of annual bluegrass, only three measurements were taken for annual bluegrass NDVI. The average of the sample measurements in each plot was utilized as the NDVI value of each plot. NDVI data was taken every two weeks concurrent with visual assessments.

Dark green color index was taken with the customized Green Index function of the TCM 500 NDVI turf color meter. The Green Index was first set at the beginning of the experiment in the spring 2014. A 6 score was taken as the minimum acceptable color and the setting was not changed throughout the two year experimental period. The turf color meter offers Green Index readings according to the same standard and gives Green Index readings from 1 to 9. As with NDVI data, four sample measurements were randomly taken in each plot for creeping bentgrass DGCI data and due to the rather small population of annual bluegrass, only three samples per plot were taken for annual bluegrass DGCI data. The average of the samples per plot was utilized as the DGCI value per plot. Green Index data was taken every two weeks.
Grid counting was performed to offer an objective presentation of the percent coverage of the annual bluegrass population in addition to the visual assessment. The grid was 0.91 by 0.91 m with 121 intersections at a 76.2 by 76.2 mm spacing. Two grids were utilized to cover the whole plot. As a result, there were a total of 242 intersections per plot. During the counting process, any presence of annual bluegrass living tissue within the range of a 24.26 mm diameter circle at the intersection point was considered a positive count. The total positive counts of annual bluegrass living tissue divided by 242 was taken as the percent coverage of the annual bluegrass population. The grid counting was performed by the same person throughout the two-year experimental period and was conducted before the initial treatments were applied and every month after the initial treatment.

Digital image analysis is a new method for turfgrass surface quality evaluation. Richardson et al. (2001) has found that digital image analysis has lowered the mean variance of percent coverage of bermudagrass from 99.12 using visual assessment and 13.18 using the grid counting method to 0.65, which means digital image analysis is more accurate and objective in determination of turfgrass coverage. A 0.5 by 0.6 m light photo box (Digital analysis light box assembly, NexGen Turf Research, Albany, Oregon) and a digital camera (Sony SLT-A57, SAL1855 lens, Sony Corp.) were utilized to take one photo from each plot every two weeks. One portable power pack (Powerpack 600, Duracell, Bethel, CT) was attached to the light box to power four compact fluorescent bulbs with 63662 cd as a constant light source in the box. The camera was set at manual model and a 3568 × 2368 digital image was taken with 0.62 second exposure time and 100 ISO Sensitivity. Photos were saved into Joint Photographic Experts Group (JPG)
format, loaded into a personal computer and analyzed with ImageJ (ImageJ, U. S. National Institutes of Health, Bethesda, MD). The red, green and blue (RGB) levels were exported and converted into Hue, Saturation and Brightness (HSB) parameters. The HSB values would be used in the Dark Green Color Index (DGCI) for turfgrass color analysis. Coverage readings were counted as green color pixel numbers by imageJ.

Analysis of all the data was performed with SAS 9.3 (SAS Institute Inc., Cary, NC) and Microsoft Excel (Microsoft Office Professional Plus 2013). ODS Graphics was used for the test of the assumptions of ANOVA and PROC GLM was utilized in SAS for ANOVA test. Fisher’s protected least significant difference (LSD) values for mean comparisons (p ≤ 0.05). Significant interactions were detected between years and the treatments; thus, data from each year were analyzed and discussed separately.

Results

*Creeping Bentgrass Color/Quality*

Creeping bentgrass color/quality has been evaluated by visual scoring and the NDVI, Green Index and digital image analysis methods. One objective was to test the effects of higher methiozolin rates on creeping bentgrass safety in the springs. A second objective was to evaluate the effect of nitrogen rates on creeping bentgrass spring green-up and the interaction between these two factors. There were similarities among the different methods used for creeping bentgrass color measurements. Overall, there were more significant effects (p ≤ 0.05) from methiozolin rates in 2014 and more significant effects (p ≤ 0.05) from nitrogen rates in 2015. In both years, there were significant interactions (p ≤ 0.05) between these two factors on limited dates.
Table 3.3 shows the results of the NDVI measurements on creeping bentgrass in 2014. There were no significant differences between plots according to the initial measurement before any treatments were applied on April 23, 2014. Two WAIT, May 9, there were already significant differences between methiozolin rates (p = 0.0053) and nitrogen rates (p = 0.0031) with only one application of each treatment. However, there were no significant interactions between the two factors. The significant effect of methiozolin rates on the NDVI of creeping bentgrass lasted until twelve WAIT, and the significance of nitrogen rates on color/quality lasted until ten WAIT. The only significant interaction between factors was four WAIT, May 24 in 2014. In 2015, the NDVI of creeping bentgrass was only significantly difference between methiozolin rates before the treatments (p = 0.0120), no other dates show significant effects on NDVI ratings from methiozolin rates (Table 3.4). Nitrogen rates, on the other hand, had significant effects on the NDVI of creeping bentgrass at 2, 4, and 6 WAIT in 2015 (Table 3.4). There was also only one rating date with significant interactions between factors, which was six WAIT, June 18, 2015 (Table 3.4). Since the interaction between the two factors was not significant on most of the rating dates during the two years of experiment, the effects of methiozolin rates and nitrogen rates on the NDVI of creeping bentgrass will be discussed separately for both years.

Figure 3.1 shows the NDVI of creeping bentgrass as affected by methiozolin rates from two WAIT to twelve WAIT in 2014 and 2015. According to the ANOVA results from Table 3.3, was a significant difference between methiozolin rates from two WAIT to ten WAIT. In Figure 3.1 (a), the NDVI of creeping bentgrass decreases with higher methiozolin rate. The 1.06 kg a.i. ha⁻¹ methiozolin rate had a significantly lower NDVI of
creeping bentgrass than all the other methiozolin rates through the entire experimental period in 201. The 0.80 kg a.i. ha\(^{-1}\) methiozolin rate had a significantly lower NDVI of creeping bentgrass than the untreated methiozolin at four WAIT and six WAIT. The NDVI of creeping bentgrass at the 0.53 kg a.i. ha\(^{-1}\) methiozolin rate was significantly lower than the no methiozolin control at four WAIT in 2014. In 2015, there were no significant differences between methiozolin rates on any rating dates [Figure 3.1 (b)], which matches the ANOVA results from Table 3.4.

Figure 3.2 shows the effects of nitrogen rates on the NDVI of creeping bentgrass in 2014 and 2015. In Figure 3.2 (a), the NDVI of creeping bentgrass increases with a higher nitrogen rate applied, and there was significant differences between the 24.4 kg N ha\(^{-1}\) and the other two lower rates from two WAIT to eight WAIT. There was no significant difference between the 6.1 kg ha\(^{-1}\) and 12.2 kg N ha\(^{-1}\) on the NDVI of creeping bentgrass (also Table 3.3). As air temperatures increased in spring, there was a decrease of creeping bentgrass NDVI for all treatments and no significant difference between nitrogen rates at ten and twelve WAIT in 2014. The effects of nitrogen rates on the NDVI of creeping bentgrass was more complicated in 2015. From two WAIT to four WAIT, the NDVI of creeping bentgrass increased with increasing nitrogen rate. At six WAIT, there was still a significant difference between nitrogen treatments (p = 0.0486, Table 3.4), with the 12.2 kg N ha\(^{-1}\) showing the highest creeping bentgrass NDVI. The NDVI of the 12.2 kg N ha\(^{-1}\) was significantly higher than 6.1 kg N ha\(^{-1}\) but not significantly higher than 24.4 kg N ha\(^{-1}\). After eight WAIT, there were no longer any significant differences among nitrogen rates [Figure 3.2 (b)].
Table 3.5 shows the ANOVA results of green index of creeping bentgrass. Since both the NDVI and green index were taken with the same device, there was a high correlation between these two sets of data. The significance level of methiozolin on the green index ratings for creeping bentgrass, even though lower than the NDVI data, are still significantly different (p ≤ 0.05) from two WAIT to ten WAIT in 2014. There was also significant differences among nitrogen rates from two WAIT to ten WAIT in 2014. As with the NDVI data, there were no significant differences among methiozolin rates on creeping bentgrass green index in 2015, and only two days where there were significant effects from nitrogen rates, which were four WAIT (p < .0001, June 3) and ten WAIT (p = 0.0129, July 15 (Table 3.6).

In Figure 3.3, the green index of creeping bentgrass under different methiozolin rates are provided for both 2014 and 2015. Even though the green index data have a lower significance level than the NDVI data, the highest methiozolin rate at 1.06 kg a.i. ha⁻¹ still caused a significantly lower creeping bentgrass color than all the other lower rates. In 2014, when treated with 0.80 kg a.i. ha⁻¹ methiozolin, the green index of creeping bentgrass was significantly lower than the no methiozolin control only four WAIT and six WAIT [Table 3.3 (a)]. In Table 3.3 (b), all the methiozolin treatments have a lower creeping bentgrass green index than the no methiozolin controls at two WAIT, which is different than the NDVI data. The green index ratings on the remainder of the rating dates are the same as the NDVI data in Figure 3.1 (b), indicating there are no significant differences among the methiozolin rates on creeping bentgrass color in 2015.
Figure 3.4 shows the effects of nitrogen rates on the creeping bentgrass green index in 2014 and 2015. Like the NDVI results, the green index of creeping bentgrass also increases significantly with higher nitrogen rate. In 2014, green index ratings showed the 24.4 kg N ha\(^{-1}\) had significantly darker green color than lower rates from two WAIT to ten WAIT. This was two weeks longer than represented by the NDVI of creeping bentgrass, and the 12.2 kg N ha\(^{-1}\) was significantly greener than the 6.1 kg N ha\(^{-1}\) at six WAIT, which was not seen in the NDVI data. Due to warmer weather in 2015, creeping bentgrass greened up earlier and faster than in 2014, so the only significant effect among nitrogen rates on creeping bentgrass color was at four WAIT and ten WAIT. On both rating dates, the 12.2 and 24.4 kg N ha\(^{-1}\) treatments had significantly greener color than creeping bentgrass at the 6.1 kg N ha\(^{-1}\). On June 3, 2015, the 24.4 kg N ha\(^{-1}\) resulted in significantly greener color than the 12.2 kg N ha\(^{-1}\). Visual assessment ratings on creeping bentgrass color are provided in Tables 3.7 and 3.8 for 2014 and 2015. In both years, the visual assessment of creeping bentgrass color/quality on the experimental area prior to initial treatments rated a 6.0 with no variance detected among plots. There was a significant difference (p ≦ 0.050 among methiozolin rates from two WAIT to eight WAIT in 2014, and on only one rating date (p = 0.0205, June 3 in 2015, which matches both the NDVI and green index measurements. There were more significant differences (p ≦ 0.050) among nitrogen rates on visual assessment of color/quality ratings, which appears from two to ten WAIT in 2014 and from two to twelve WAIT in 2015. Like the color meter measurements, the visual assessment resulted in limited interactions between the two factors as well. The only significant interaction was at two WAIT in 2014 (p = 0.0065) and four WAIT in 2015 (p = 0.0074).
Figure 3.5 shows the effect of methiozolin rates on the visual assessment of color/quality in 2014 and 2015. In 2014, the 0.80 kg a.i. ha\(^{-1}\) and the 1.06 kg a.i. ha\(^{-1}\) methiozolin rates had significantly lower color/quality scores compared to the no methiozolin control and the 0.53 kg a.i. ha\(^{-1}\) methiozolin treatment. There was no significant difference between the no methiozolin control and the 0.53 kg a.i. ha\(^{-1}\) methiozolin treatment at two and four WAIT, which matches the measurement from the color meter [Figure 3.1(a) and Figure 3.3 (a)]. At six and eight WAIT, the visual color/quality scores of creeping bentgrass started to increase at the higher methiozolin rates, which was not similar to the NDVI and the green index data. At 10 and 12 WAIT, the visual assessment of color/quality of creeping bentgrass decreased due to increased temperatures and no more significant differences were observed among the methiozolin rates, which matches the color meter measurements. In 2015, the visual color/quality of creeping bentgrass increased with higher methiozolin rates, however there is no significant difference among the methiozolin treatments according to the ANOVA results (Table 3.8).

Despite of some differences between the visual assessment and the color meter measurements on the effects of methiozolin rates on the color/quality of creeping bentgrass, the effects of nitrogen rates on the visual color/quality scores of creeping bentgrass generally matches the color meter measurements but with more significance. In Figure 3.6 (a), the 24.4 kg N ha\(^{-1}\) treatments had significantly higher color/quality scores on creeping bentgrass than the 6.1 kg N ha\(^{-1}\) and the 12.2 kg N ha\(^{-1}\) treatments from two WAIT to six WAIT. There was no significant difference between the 12.2 kg N ha\(^{-1}\) and the 24.4 kg N ha\(^{-1}\) treatments from eight WAIT to ten WAIT, but the two higher rates still
had significantly higher creeping bentgrass color/quality than the 6.1 kg N ha\(^{-1}\) treatment. Compared to the limited significant effects of nitrogen rates on creeping bentgrass color detected by the NDVI in Figure 3.2 (b) and by the green index in Figure 3.4 (b), the visual assessment method showed more creeping bentgrass color/quality differences among nitrogen rates in 2015 [Figure 3.6 (b)]. The highest nitrogen rate, 24.4 kg ha\(^{-1}\), had significantly higher creeping bentgrass color/quality scores than all the lower nitrogen rates from four WAIT to the end of the experiment (12 WAIT). The 12.2 kg N ha\(^{-1}\) resulted in significantly higher color/quality scores than the 6.1 kg N ha\(^{-1}\) from two WAIT to eight WAIT.

Comparing the three creeping bentgrass color measurement methods, there are great similarities between the NDVI data and green index data because they are both taken with the spectrum color meter. The visual assessment method showed the same effects from nitrogen rates but with an even higher significant level compared with the spectrum color meter methods. However, the effect of methiozolin rates on the color/quality scores of creeping bentgrass from the visual assessment was almost the opposite of the spectrum color meter methods. A third method was added to potentially increase the accuracy of the creeping bentgrass color measurement, and is referred to as the digital image color analysis (DIA).

Table 3.9 shows the ANOVA results of the DIA of creeping bentgrass color in 2014. There were significant differences (p \(\leq\) 0.05) among methiozolin rates from two WAIT to six WAIT and significant differences (p \(\leq\) 0.05) among nitrogen rates from four WAIT to six WAIT. There was no significant interactions between these two factors.
except at four WAIT (p = 0.02970. In 2015 (Table 3.10), there were no significant differences among methiozolin rates. There was a significant difference among nitrogen rates only at four WAIT just like reported for the green index of creeping bentgrass (Table 3.6). There was also no significant interactions between methiozolin rates and nitrogen rates according to the DIA of creeping bentgrass color from 2015 (Table 3.10).

Figure 3.7 shows the effects of methiozolin rates on the DIA of creeping bentgrass color in 2014 and 2015 (Tables 3.9 and 3.10). In 2014, the color of creeping bentgrass decreased significantly (p ≤ 0.05) with higher methiozolin rates from two WAIT to six WAIT. After the last application of methiozolin at six WAIT, the color differences as measured by DIA on creeping bentgrass caused by methiozolin were not as apparent with time with no significant difference among methiozolin rates from eight WAIT to twelve WAIT [Figure 3.7(a)]. In 2015, there was no significant difference between methiozolin rates on any rating dates during the experiment period [Figure 3.7(b)].

Figure 3.8 is the DIA of creeping bentgrass color as affected by difference nitrogen rates. Unlike the NDVI, the green index and the visual assessment data, there was much less significance on color among nitrogen rates were at four WAIT and six WAIT in 2014 and four WAIT in 2015. The DIA of creeping bentgrass color with the 24.4 kg N ha⁻¹ was significantly higher than the 12.2 kg N ha⁻¹ on for all three of the latter rating dates (four and six 6 WAIT in 2014 and four WAIT in 2015). The 12.2 kg N ha⁻¹ had a significantly higher DIA than the 6.1 kg N ha⁻¹ at four WAIT in both years. On the other rating dates during the entire experiment, there was a trend for slightly higher
DIA color ratings of creeping bentgrass with higher nitrogen rates, but not on a statistical significant level.

The results from the DIA of creeping bentgrass color matches the findings from the NDVI and green index data, especially the effects of methiozolin rates on the color of creeping bentgrass.

In conclusion, the color of creeping bentgrass decreased significantly with higher methiozolin rates in 2014, and in a warmer year like 2015, there was less of a significant effect or no significant influence of higher methiozolin rates on creeping bentgrass color. As to nitrogen rates effects on creeping bentgrass color/quality, all the methods shows the same result, that the color of creeping bentgrass increased significantly with higher nitrogen rates, especially within eight WAIT. Among all the treatments, there was no noticeable phytotoxicity or discoloration on the creeping bentgrass in any plots during the entire experiment period over two years.

Annual Bluegrass Color

Annual bluegrass color was measured to determine the effect of methiozolin on annual bluegrass color/quality and efficacy/control. One of the effects of methiozolin on annual bluegrass is chlorosis. The annual bluegrass turns yellow then declines slowly until taken over by creeping bentgrass or by new annual bluegrass from seed bank germination. The discoloration (yellowing/necrosis) of annual bluegrass shows how fast the chlorosis is happening and it is one way to determine how efficient methiozolin is on annual bluegrass efficacy/control. Overall, the color of annual bluegrass decreased significantly (p ≤ 0.05) with higher methiozolin rates from two WAIT to eight WAIT. There was a
significant positive effects of nitrogen rates (p ≤ 0.05) on the annual bluegrass color on certain rating dates in both years during the experimental period.

Table 3.11 shows the results of the NDVI of annual bluegrass effected by methiozolin rates and nitrogen rates in 2014. According to the ANOVA results, there was a significant difference among methiozolin rates from two WAIT to eight WAIT (p < .0001). There was also a significant difference among nitrogen rates at two WAIT and six WAIT (p ≤ 0.05), and a significant interaction between these two factors only at two WAIT (p ≤ 0.05) in 2014. In 2015, the significant effects (p ≤ 0.05) of methiozolin rates on annual bluegrass color lasted from two WAIT to eight WAIT and appeared again at twelve WAIT (Table 3.12). There were also more rating dates with significant differences among nitrogen rates according to the ANOVA results from four WAIT to the end of the experiment period in 2015 (Table 3.12). The interaction between factors was still limited in 2015 and only occurred on the last day of the experiment (p = 0.0068, July 29).

Figure 3.9 shows the effects of methiozolin rates on the NDVI of annual bluegrass in 2014 and 2015. In 2014, the NDVI of annual bluegrass decreased significantly at the higher methiozolin rates. All methiozolin rates had significantly lower annual bluegrass NDVI from two WAIT to six WAIT compared with the no methiozolin control. The highest methiozolin rate, 1.06 kg a.i. ha⁻¹, which is two times of the protocol rate, had significantly lower NDVI ratings than the 0.53 kg a.i. ha⁻¹ methiozolin rate at two WAIT and six WAIT. The 0.80 kg a.i. ha⁻¹ methiozolin rate which is 1.5 times the protocol rate had significantly lower NDVI ratings than the 0.53 kg a.i. ha⁻¹ methiozolin rate at six WAIT [Figure 3.9 (a)]. Figure 3.9 (b) shows the NDVI of annual bluegrass as influenced
by methiozolin rates in 2015, which was similar to the results from 2014. The only differences were the 0.53 kg a.i. ha\(^{-1}\) methiozolin rate was not significant different than the no methiozolin control and the 0.80 kg a.i. ha\(^{-1}\) methiozolin rate reacted slower on annual bluegrass color than 2014. Both the NDVI data from 2014 and 2015 shows that the color of annual bluegrass declines with higher methiozolin rates. This means that the higher methiozolin rate that is applied, the quicker annual bluegrass responses to it.

As the positive effect of nitrogen rate on the color of creeping bentgrass (Figure 3.2), higher nitrogen rates also promoted a positive color response of annual bluegrass. In Figure 3.10, the NDVI of annual bluegrass increased significantly with higher nitrogen rates in both 2014 and 2015. However, according to the ANOVA results (Table 3.11), there were actually only two rating dates in 2014 with significant difference among nitrogen rates at two WAIT (p = 0.0009) and six WAIT (p = 0.0002). On both rating dates, the 24.4 kg N ha\(^{-1}\) was significantly higher than the other two lower rates. There was no significant difference between the 6.1 kg ha\(^{-1}\) and the 12.2 kg N ha\(^{-1}\). In 2015, according to the ANOVA results from Table 3.12, there was a significant effect of nitrogen rates from four WAIT to the end of the experiment. On the latter rating dates, the highest nitrogen rate, 24.4 kg ha\(^{-1}\), had significantly higher annual bluegrass NDVI ratings than the lowest rate, 6.1 kg ha\(^{-1}\). The 12.2 kg N ha\(^{-1}\) had a NDVI between the other two nitrogen rates. Only at six WAIT and twelve WAIT did the 12.2 kg N ha\(^{-1}\) have a significantly higher NDVI of annual bluegrass than the 6.1 kg N ha\(^{-1}\) and it was not significantly different from the 24.4 kg N ha\(^{-1}\).
The green index of annual bluegrass as influenced by methiozolin rates and nitrogen rates in 2014 and 2015 are presented in Tables 3.13 and Tables 3.14, respectively. The ANOVA results from 2014 are highly similar to the results of NDVI. There was a significant difference among methiozolin rates from two WAIT to eight WAIT (p = 0.0001) and a significant difference among nitrogen rates at two WAIT (p = 0.0097) and six WAIT (p = 0.0245). There was also limited interactions between the two factors on the green index only at eight WAIT (p = 0.0090). However, the green index data of annual bluegrass from 2015 had more significant results than the NDVI data. There was a significant difference among methiozolin rates from two WAIT to eight WAIT and also at twelve WAIT. There are two rating dates with significant effects of nitrogen rates on the green index of annual bluegrass at four WAIT (p = 0.0155) and at ten WAIT (p = 0.0150) in 2015, but no significant interactions.

Figure 3.11 shows the effects of methiozolin rates on the green index of annual bluegrass in 2014 and 2015. Compared with the NDVI data (Figure 3.9), the effects of methiozolin treatments on the green index of annual bluegrass reflect similar trends but only at a higher significant level. For example, at eight WAIT in 2014, the 0.80 kg a.i. ha\(^{-1}\) methiozolin rate had significantly lower green index ratings than the no methiozolin control, and the green index of the 1.06 kg a.i. ha\(^{-1}\) methiozolin rate was significantly lower than the 0.80 kg a.i. ha\(^{-1}\) methiozolin rate. The annual bluegrass green index data from 2015 shows even more significant differences than the NDVI data of 2015. In Figure 3.11 (b), both the 0.80 kg ha\(^{-1}\) and the 1.06 kg ha\(^{-1}\) methiozolin treatments resulted in significantly lower ratings than the no methiozolin controls from two WAIT to eight WAIT. The protocol methiozolin rate, 0.53 kg a.i. ha\(^{-1}\), had significantly lower ratings
than the no methiozolin control at eight WAIT. One observation was that at the end of the experiment in 2015(12 WAIT), the green index of annual bluegrass starts to significantly increase with higher methiozolin rates.

The effects of nitrogen rates on the green index of annual bluegrass (Table 3.12) was very similar to the results from the NDVI data. The highest nitrogen treatment, 24.4 kg ha\(^{-1}\), had significantly higher green index ratings than the lower rates two WAIT and six WAIT in 2014, and four WAIT and ten WAIT in 2015. There was no significant difference between the 6.1 kg N ha\(^{-1}\) and the 12.2 kg N ha\(^{-1}\) on the green index of annual bluegrass on all dates in both 2014 and 2015.

Table 3.15 shows the visual assessment of annual bluegrass color/quality in 2014. On April 23, visual assessment was taken on all plots before initial applications. There was no variance of the annual bluegrass color/quality among plots as all the annual bluegrass scored 5.5. After the first application of methiozolin, there was a significant difference (p ≤ 0.05) among methiozolin rates from two WAIT to the end of the experiment in 2014. The difference in visual assessment among nitrogen rates was also significant from two WAIT (p = 0.0002) to four WAIT (p = 0.0226). Unlike the spectrum light meter data, there was a significant interaction between two factors from two WAIT to six WAIT (p ≤ 0.05). In 2015, (Table 3.16), there was some variance in the visual assessment among plots before initial treatments, but not at a significant level. The significant difference among methiozolin rates started from two WAIT and lasted to the last week of the experiment just like the visual assessment data from 2014. The significant effects among the nitrogen rates also lasted from two WAIT to eight WAIT in
In 2015 (Table 3.16), there were significant interactions between factors at six WAIT (p = 0.0459, June 18), and eight WAIT (p = 0.0082, July 1).

Figure 3.13 shows the effects of methiozolin rates on the visual assessment ratings of annual bluegrass in 2014 and 2015. In Figure 3.13 (a), the visual color/quality ratings for annual bluegrass in 2014 decreased significantly (p ≤ 0.05, Table 3.15) with higher methiozolin rates, and there were mainly two groups among all methiozolin rates. The first group was the 0.53 kg a.i. ha⁻¹ methiozolin rate had significantly lower annual bluegrass visual color/quality only from two WAIT to six WAIT. After eight WAIT, the annual bluegrass at the 0.53 kg a.i. ha⁻¹ methiozolin treatment showed no significant difference to the no methiozolin control. The second group consists of higher two methiozolin rates, 0.80 kg ha⁻¹ and 1.06 kg ha⁻¹. These two rates had significantly lower annual bluegrass color/quality than both the first group and the no methiozolin control. There was no significant difference between these two higher rates except at four WAIT, which was after two applications of methiozolin in 2014. In Figure 3.13 (b) (2015), the visual assessment ratings of annual bluegrass first decreased significantly with higher methiozolin rates from two WAIT to eight WAIT then started to increase after 8 WAIT. During the first eight weeks after the initial application (Figure 13, 2015), the visual color/quality ratings of annual bluegrass at the 1.06 kg a.i. ha⁻¹ methiozolin rate were always significantly lower than the no methiozolin control and all the other lower rates. The two lower methiozolin rates, 0.53 kg ha⁻¹ and 0.80 kg a.i. ha⁻¹, had similar effects on annual bluegrass color/quality from two WAIT to four WAIT and were significantly different from each other from six WAIT to eight WAIT. In the later weeks of the experiment (Figure 3.13, 2015), the visual assessment of annual bluegrass color/quality
started to decrease and the color/quality of methiozolin treated annual bluegrass started to increase. Even though there was still a significant difference among methiozolin rates, the difference was relatively small compared to the color/quality differences at six WAIT and eight WAIT.

Figure 3.14 provides the visual assessment ratings of annual bluegrass as affected by nitrogen rates. In 2014, there was only significant effects from nitrogen treatments two WAIT and four WAIT according to the ANOVA test (Table 3.15). After only one application of methiozolin (two WAIT), there was no significant difference in the visual assessment of color/quality between the 6.1 kg N ha\(^{-1}\) and 12.2 kg N ha\(^{-1}\). The annual bluegrass at the 24.4 kg N ha\(^{-1}\) had a significantly higher visual color/quality rating than the two lower nitrogen rates. However, this positive effect of high nitrogen on the color/quality of annual bluegrass did not continue on. After the second nitrogen application (four WAIT), both the 12.2 kg ha\(^{-1}\) and 24.4 kg N ha\(^{-1}\) treatments had lower color ratings than the 6.1 kg N ha\(^{-1}\). From six WAIT to twelve WAIT (Figure 3.13, 2014), even though the 12.2 kg N ha\(^{-1}\) treatment appeared to have a lower visual color/quality rating on annual bluegrass than the other nitrogen rates, there was no statistically significant difference among nitrogen treatments according to the ANOVA results (Table 3.15). Unlike the visual assessment data in 2014, the visual assessment color/quality ratings of annual bluegrass as affected by methiozolin rates in 2015 (Table 3.16 and Figure 3.14) are more similar to the data taken by the spectrum color meter. From two WAIT to six WAIT, the color/quality of annual bluegrass increased with higher nitrogen rates. This was especially true at the highest nitrogen rate, 24.4 kg ha\(^{-1}\), which had a significantly higher color/quality rating than the two lower rates until six WAIT. At eight
WAIT, even the 24.4 kg N ha\(^{-1}\) had a color/quality rating significantly higher than 12.4 kg N ha\(^{-1}\), but already no difference between the 6.1 kg ha\(^{-1}\) and the 24.4 kg N ha\(^{-1}\). At ten WAIT, there were already no significant differences among any of the nitrogen rates. 

There were no significant differences between 6.1 kg ha\(^{-1}\) and 12.2 kg N ha\(^{-1}\) treatments during the entire experiment period in 2015 (Table 3.16 and Figure 3.14). The lack of color/quality differences of annual bluegrass among the nitrogen treatments at the end of the experiment (12 WAIT) in 2015 can be explained by the lack of representative annual bluegrass patches for making visual color/quality assessments. After ten WAIT, the annual bluegrass population in the plots, especially those under a high methiozolin rate, were too low to be measured by the spectrum color meter or visually. From the casual observation, what could be measured at the end of the experimental period were patches of most likely perennial type annual bluegrass, which has higher density, faster vegetation growth and is more resistant to spring applications of methiozolin.

Table 3.17 shows the DIA of annual bluegrass as affected by methiozolin and nitrogen treatments in 2014. According to the ANOVA results, there are significant differences among methiozolin rates from two WAIT to six WAIT (p \(\leq\) 0.05), and no significant difference in the DIA before the first methiozolin application and after the last application on June 7, 2014. There were significant differences among nitrogen rates on the DIA of annual bluegrass at four WAIT (p = 0.0334) and six WAIT (p = 0.0022) after two and three applications of nitrogen at each rate. No significant interactions occurred between these two factors on any dates according to the DIA results. Table 3.18 shows the DIA of annual bluegrass color in 2015. There are more dates in 2015 with significant difference between methiozolin treatments and nitrogen treatments than 2014. According
to the ANOVA results, there were significant differences ($p \leq 0.05$) from two WAIT to eight WAIT and also on the last day of the experiment (12 WAIT). Significant differences among nitrogen rates lasted from four WAIT to the end of the experiment (12 WAIT). No significant interactions were detected in 2015 either except twelve WAIT.

Figure 3.15 shows the effects of methiozolin rates on the DIA of annual bluegrass color in both 2014 and 2015 (Table 3.17 and Table 3.18). In the first six weeks after the initial application of methiozolin, the DIA ratings of annual bluegrass color decreased significantly with higher methiozolin rates in both years. The protocol methiozolin rate, 0.53 kg a.i. ha$^{-1}$, had a significantly lower DIA color rating than the no methiozolin control in 2014 from two to six WAIT and no effect on the DIA between the no methiozolin controls in 2015. The higher methiozolin rate of 1.06 kg a.i. ha$^{-1}$, resulted in a significantly lower DIA color rating than the protocol rate. The 0.80 kg a.i. ha$^{-1}$ methiozolin rate had a DIA rating in between the low and high methiozolin rates with no significant difference compared with the 1.06 kg ha$^{-1}$ methiozolin rate in 2014 [Figure 3.15 (a)]. The effects of methiozolin rates on the DIA of annual bluegrass color in 2015 can be separated into three parts [Figure 3.15 (b)]. From two WAIT to eight WAIT in 2015, the DIA of annual bluegrass color decreased with higher methiozolin rates with the 1.06 kg ha$^{-1}$ methiozolin rate resulting in significantly lower DIA ratings than all the other rates from two to four WAIT. Also, both the 0.80 kg ha$^{-1}$ and the 1.06 kg ha$^{-1}$ methiozolin rates resulted in significantly lower DIA ratings than the no methiozolin and 0.53 kg ha$^{-1}$ methiozolin treatments from six to eight WAIT in 2015. In the second part at ten WAIT, was no significant difference among methiozolin rates [Table 3.18, Figure 3.15 (b)]. In the third part at twelve WAIT in 2015, the DIA rating for annual bluegrass started to
increase at the higher methiozolin rates, with the 1.06 kg ha\(^{-1}\) and the 0.80 kg ha\(^{-1}\) methiozolin rates showing a significantly higher DIA rating than the no methiozolin control.

The DIA of annual bluegrass color increased significantly with increasing nitrogen rates between four WAIT and six WAIT in 2014. The 24.4 kg N ha\(^{-1}\) was significantly higher than the 6.1 kg N ha\(^{-1}\). There were no significant differences observed on the other dates in 2014 [Figure 3.16 (a)]. The DIA of annual bluegrass color in 2015 [Figure 3.16 (b), Table 3.18], however had significant differences among nitrogen rates from four WAIT to the end of the experiment. Except for the data at six WAIT, the DIA of annual bluegrass color increased significantly with higher nitrogen rates on all the other rating dates and the 24.4 kg N ha\(^{-1}\) treatment had significantly higher DIA color than the 6.1 kg N ha\(^{-1}\) treatment. On most of the rating dates, there were no significant differences between the 6.1 kg N ha\(^{-1}\) and 12.2 kg N ha\(^{-1}\), and between 12.2 kg ha\(^{-1}\) and 24.4 kg N ha\(^{-1}\).

In conclusion, there were more similarities in color measurements taken with the spectrum light meter, namely the NDVI data and the green index data, and the DIA data. The visual assessment ratings for color/quality of annual bluegrass provided similar results only at an even higher significance level. Overall, the color of annual bluegrass decreased significantly at higher methiozolin rates. The effects of nitrogen rates on the color of annual bluegrass were similar to the effects of nitrogen rates on the color of creeping bentgrass in that higher nitrogen rates increased annual bluegrass green color. This means that higher nitrogen fertility may have promoted annual bluegrass growth and
slowed or prevented annual bluegrass from the chlorosis and/or necrosis caused by methiozolin. The lack of interaction between methiozolin rates and nitrogen rates means that the effects of methiozolin on the color of annual bluegrass was not affected by the nitrogen applied. This means the more discoloration of annual bluegrass at the higher methiozolin rates will occur with little if any influence of the greens fertilization program.

**Annual Bluegrass Population**

Annual bluegrass population has been evaluated by visual assessment and by grid the counting method. Visual assessment of the annual bluegrass population was made before the initial spring methiozolin and nitrogen treatments, and every two weeks after thereafter. Grid counting was conducted before the initial treatment and every month after that with a grid which is the same size as the plot and has a total of 242 intersections (22 by 11). The annual bluegrass population was transformed by subtracting the initial percentage of annual bluegrass from the percent annual bluegrass population on the rating date to minimize the influence from the variance in the original annual bluegrass population at the beginning of the experiment. The transformed data stands for the change of percent annual bluegrass population at each rating date. If it is a positive number, it means there was an increase of annual bluegrass population from the day before the first application to that rating date. Otherwise, a negative number means there was a decrease of the annual bluegrass population from the day before the first application to that rating date. There are six dates for the visual assessment of the change of the annual bluegrass population in each year, which means the percent coverage of
annual bluegrass was measured visually six times after the first application in each year at two week intervals. Similarly, the grid counting was conducted three times at monthly intervals after the first application of spring methiozolin and nitrogen.

Table 3.19 shows the change in the annual bluegrass population by visual assessment from two WAIT to twelve WAIT in 2014. The ANOVA result shows that there were significant differences among methiozolin rates from six WAIT (p < .0001, June 7) to the end of the experiment period (p < .0001, July 19). Nitrogen rates also had significant effects (p ≤ 0.05) on the change of visual assessment of the annual bluegrass population from four WAIT to eight WAIT. There was significant interactions between the two factors at eight WAIT (p = 0.0415, June 21) and ten WAIT (p = 0.0214, July 5). The effect of methiozolin rates on the change in the visual assessment of the annual bluegrass population worked slower in 2015 than in 2014. Significant differences (p < .0001) among methiozolin rates started to show two weeks later at eight WAIT in 2015 instead of six WAIT as in 2014 (Table 3.20). Unlike 2014, there were no significant differences among nitrogen rates nor significant interactions between methiozolin rates and nitrogen rates in 2015 (Table 3.20).

Figure 3.17 shows the change of visual assessment of the annual bluegrass population under difference methiozolin rates in 2014 and 2015. In Figure 3.17 (a), the values were positive at two WAIT in 2014 meaning there was an increase in the annual bluegrass population with all methiozolin treatments with only one application of methiozolin with no significant difference among treatments. Four WAIT, the annual bluegrass population started to decrease, but there were still no significant differences
among treatments at this point of the experiment in 2014. From six to twelve WAIT, there were significant differences among the methiozolin rates (Table 3.19) and a greater decrease of visual annual bluegrass population at the higher methiozolin rates. The no methiozolin treatments showed no decrease in the annual bluegrass population from six WAIT to twelve WAIT compared to all the other methiozolin rates. This means the annual bluegrass population without any methiozolin treatment remains the same or actually increases in the spring. The protocol methiozolin rate of 0.53 kg ha\(^{-1}\) caused a negative change or decrease in the annual bluegrass population from six WAIT to twelve were significantly lower than the no methiozolin treatment but significantly less than the higher two higher rates. On the other hand, 0.80 kg ha\(^{-1}\) methiozolin rate had significantly less decrease in annual bluegrass population than the highest 1.06 kg ha\(^{-1}\) methiozolin rate at six WAIT. There were no significant differences between the two higher methiozolin rates after eight WAIT according to the visual assessment ratings of the annual bluegrass population. The visual assessment ratings for the annual bluegrass population for 2015 had a lot of similarities to the results from 2014. The main difference was that the effects of methiozolin rates on the change of visual assessment of the annual bluegrass population occurred much later during the experimental period in 2015 [Figure 3.17 (b)]. This was possibly due to the warmer weather in late April and early May in 2015, which provided a very suitable environment for annual bluegrass to encroach from tillers and germination from the seed bank. Despite of the delay in time, there was still a significant difference among methiozolin rates at ten WAIT and twelve WAIT in 2015. The change in the annual bluegrass populations’ assessment decreased 25-30% in both 2014 and 2015 as affected by methiozolin rates.
Figure 3.18 shows the effect of nitrogen rates on the change of visual assessment of the annual bluegrass population in 2014 and 2015 (Table 3.19). After the first application of the methiozolin and nitrogen treatments, there was slight increase in the annual bluegrass population and no significant difference between each rate at two WAIT in 2014. At four WAIT, the change in the annual bluegrass population with the 12.2 kg N ha\(^{-1}\) and the 24.4 kg N ha\(^{-1}\) started to decrease or become negative. The change in the annual bluegrass population with the 6.1 kg N ha\(^{-1}\) was still increasing, and was significantly higher than 24.4 kg N ha\(^{-1}\). From six WAIT to eight WAIT in 2014 [Figure 3.18 (a)], the change in the annual bluegrass population at the 6.1 kg N ha\(^{-1}\) started to decline, but the decrease of annual bluegrass population was still significantly less than higher nitrogen rate treatments. At ten WAIT, there were no significant differences among any of the nitrogen rates. However, two weeks later, at twelve WAIT, the annual bluegrass population at the 6.1 kg N ha\(^{-1}\) slightly increased and the annual bluegrass population at both the 12.2 kg N ha\(^{-1}\) and 24.4 kg N ha\(^{-1}\) continued to decrease to with an approximate – 20% change in the annual bluegrass population at the higher two nitrogen rates at twelve WAIT. There was a significant difference between the lowest nitrogen rate and the highest nitrogen rate again in the change of visual assessed annual bluegrass population. Unlike 2014, there were no significant differences among nitrogen rates in the change of visual assessment of the annual bluegrass population at all throughout the entire experimental season in 2015 although there was a decrease in the visual assessment of the annual bluegrass to an approximately - 10% change at all methiozolin rates at ten and twelve WAIT.
Grid Counting was also conducted for the measurement of annual bluegrass population. Table 3.21 and 3.22 show the ANOVA results of the change in annual bluegrass population measured by grid counting in 2014 and 2015, respectively. Due to the difficulty and time limitation, the grid counting measurement were made monthly before the first application, four WAIT, eight WAIT and twelve WAIT. After the data transformation, there were only three dates for the change of grid counting of annual bluegrass in each year. From the ANOVA results in Table 3.21, there were significant differences among methiozolin rates as early as four WAIT in 2014, instead of six WAIT in Table 3.19. The significant effect of nitrogen rates on the change of annual bluegrass population did not occur until twelve WAIT. There was a significant interaction between methiozolin rates and nitrogen rates on all three dates in 2014 according to the grid counting results. The grid counts in 2015 (Table 3.22) are more similar to the visual assessment results in 2015 (Table 3.20). There were no significant differences among methiozolin rates until eight WAIT (p \(\leq\) 0.05). There were significant differences among nitrogen rates twelve WAIT (p = 0.0454) and no significant interactions occurred between the two factors according to the grid counts.

Figure 3.19 (a) shows the change of annual bluegrass population measured by grid counting method affected by methiozolin rates in 2014. Four WAIT, after two applications of each methiozolin rate, all the methiozolin treatments had a significantly greater decrease of the annual bluegrass population than the no methiozolin treatment. There were no significant differences between each methiozolin rate at this time (four WAIT). Eight WAIT, which was two weeks after the last one of all four applications of methiozolin at each rate, there were greater decreases in the change of the annual
bluegrass population especially at the higher methiozolin rates. The protocol methiozolin rate, 0.53 kg a.i. ha\(^{-1}\), resulted in a significantly greater decrease of the annual bluegrass population than no methiozolin treatment, but still had significantly less of a decrease in the annual bluegrass population the two higher rates. There was no significant difference between the 0.80 kg a.i. ha\(^{-1}\) and the 1.06 kg a.i. ha\(^{-1}\) methiozolin rates at this point with an approximately 15-20% decrease. Two weeks later, which is four weeks after the last application of methiozolin and twelve WAIT, there were significant differences between each methiozolin rate with a decrease of the annual bluegrass population at each higher methiozolin rate with an approximate decrease of the change in the annual bluegrass population to -15-20% by twelve WAIT.

Figure 3.19 (b) shows the change of annual bluegrass population measured by grid counting method affected by methiozolin rates in 2015. Due to the warmer weather in the spring of 2015, there was still a positive change or increase in the annual bluegrass population with all treatments four WAIT, just like the visual assessment data [Figure 3.17 (b)]. Unlike the data from 2014 [Figure 3.19 (a)], there was less of a difference among methiozolin treatments in 2015 [Figure 3.19 (b)]. Eight WAIT, which was two weeks after the last application of methiozolin, all the methiozolin treatments had a significantly greater decrease on the annual bluegrass population than the no methiozolin treatment. The 2 times of the protocol methiozolin rate, 1.06 kg a.i. ha\(^{-1}\), had a significantly greater decrease on the change in the annual bluegrass population than the 0.53 kg ha\(^{-1}\) and 0.80 kg ha\(^{-1}\) methiozolin rates with no significant difference between the 0.53 kg ha\(^{-1}\) methiozolin and the 0.80 kg ha\(^{-1}\) methiozolin rates. Two weeks later (twelve WAIT), there were already no significant difference between the no methiozolin
treatment and two lower rates in the change of grid counting annual bluegrass population. However, the 1.06 kg ha methiozolin rate still had a significantly greater decrease on the annual bluegrass population than all the other lower rates.

As to the grid counting results of the change of annual bluegrass population affected by nitrogen rates, there was a significantly greater decrease of the annual bluegrass population at the highest nitrogen rate, 24.4 kg N ha⁻¹, than the other two lower rates in both 2014 [Figure 3.20 (a)] and 2015 [Figure 3.20 (b)]. The only difference between the two years was that the significant difference among the nitrogen rates did not occur until twelve WAIT in 2015, while the positive effect of a high nitrogen program on the decrease of annual bluegrass population started to occur as early as four WAIT in 2014.

In conclusion, both the visual assessment results and the grid counting results showed a significantly greater decrease of the change in the annual bluegrass population at the higher methiozolin rates. The effect of methiozolin on annual bluegrass control might not occur as early in a year with warm spring temperatures as like 2015, however by the end of twelve WAIT, there were already significant decreases in the annual bluegrass population compared with the no methiozolin treatment. A higher nitrogen fertility program, like the 24.4 kg N ha⁻¹ applied four times at two weeks interval can help decrease the annual bluegrass population. One possible explanation is that the active growth of creeping bentgrass under a high nitrogen fertility program may help to compete better over annual bluegrass. Additionally, there was no creeping bentgrass injuring or discoloration throughout the entire experimental period in both years.
Conclusions

Creeping bentgrass color measured by NDVI, green index and digital image analysis were very similar among methods, especially the effects of methiozolin rates on the color of creeping bentgrass. However, visual assessment of creeping bentgrass color showed some different results for methiozolin rates on creeping bentgrass color/quality, especially at four WAIT and six WAIT. According to the data taken by the spectrum color meter and DIA, the color of creeping bentgrass decreased significantly with higher methiozolin rates during the time of applications in a normal year like 2014. Under warmer weather conditions, as in 2015, there were no significant negative effects or decreases in creeping bentgrass color among the higher methiozolin rates compared to the protocol rate. As to the effects of nitrogen rates on creeping bentgrass color, visual assessment ratings showed the same result as other color measurements only at a higher significant level. Considering the results from all measurement methods, the color of creeping bentgrass was improved significantly with higher nitrogen rates, especially prior to ten WAIT.

The results of annual bluegrass color showed more similarities between the NDVI, green index and DIA measurements. The visual assessment of annual bluegrass color seems to provide greater differences among nitrogen treatments, just like the visual assessment for creeping bentgrass color. Despite the greater differences from visual assessment, the effects of methiozolin rates and nitrogen rates on the color of annual bluegrass were still consistent over the other three methods. The color of annual bluegrass decreased significantly with higher methiozolin rates which means higher
methiozolin rates caused more chlorosis and/or necrosis on annual bluegrass. The effects of nitrogen rates on annual bluegrass color were similar to the effects of nitrogen rates on creeping bentgrass color. Higher nitrogen rates not only increased the color of creeping bentgrass, but also annual bluegrass color. This means higher nitrogen fertility may have promoted annual bluegrass growth and countered the effects of methiozolin on the chlorosis and/or necrosis of annual bluegrass. The lack of interaction between methiozolin rates and nitrogen rates indicates that the effects of methiozolin rates on the color of annual bluegrass was not affected by the nitrogen rates. The higher methiozolin rates resulted in more discoloration of annual bluegrass regardless what fertility program was chosen.

As to the effects of methiozolin rates on the population change of annual bluegrass, both the visual assessment and the grid counting ratings showed a significant decrease in the annual bluegrass population at the higher methiozolin rates. The reduction in the annual bluegrass population with methiozolin rate might occur later in a warmer year like 2015. However by the end of twelve WAIT, there were already significant decreases of annual bluegrass population compared with no methiozolin treatment. Considering the positive effects of high nitrogen rates on the color of annual bluegrass, a high nitrogen fertility program may help with annual bluegrass growth and weakening the effects of methiozolin on annual bluegrass. On the contrary, the results the negative change in the annual bluegrass population indicate that a higher nitrogen fertility program, like 24.4 kg N ha\(^{-1}\), applied four times at two weeks interval can help enhance a decrease of the annual bluegrass population. This may be due to the active lateral growth and recuperative potential of creeping bentgrass under a high nitrogen program and this
offers competitive strength to creeping bentgrass to over compete weakened annual bluegrass.

Additionally, among all the treatments, there was no noticeable phytotoxicity or discoloration on the creeping bentgrass caused by any methiozolin rate or nitrogen rate treatments during the entire experiment over two years.
Table 3.1. All treatments of methiozolin and nitrogen rates for spring annual bluegrass control on creeping bentgrass greens.

<table>
<thead>
<tr>
<th>Methiozolin rate (kg a.i. ha$^{-1}$)</th>
<th>Nitrogen rate (kg N ha$^{-1}$)</th>
<th>6.1 (N1)</th>
<th>12.2 (N2)</th>
<th>24.4 (N4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (M0)</td>
<td>M0N1</td>
<td>M0N2</td>
<td>M0N4</td>
<td></td>
</tr>
<tr>
<td>0.53 (M1)</td>
<td>M1N1</td>
<td>M1N2</td>
<td>M1N4</td>
<td></td>
</tr>
<tr>
<td>0.80 (M2)</td>
<td>M2N1</td>
<td>M2N2</td>
<td>M2N4</td>
<td></td>
</tr>
<tr>
<td>1.06 (M3)</td>
<td>M3N1</td>
<td>M3N2</td>
<td>M3N4</td>
<td></td>
</tr>
</tbody>
</table>

† All treatments were applied at two weeks interval (twice per month) and totally four applications were made in each year.
Table 3.2. Application dates and rates of methiozolin and nitrogen treatments for spring annual bluegrass control on creeping bentgrass greens in 2014 and 2015.

<table>
<thead>
<tr>
<th>Air temp. (high/low, C)</th>
<th>M1 (kg a.i. ha⁻¹)</th>
<th>M2 (kg a.i. ha⁻¹)</th>
<th>M3 (kg a.i. ha⁻¹)</th>
<th>N1 (kg N ha⁻¹)</th>
<th>N2 (kg N ha⁻¹)</th>
<th>N4 (kg N ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24 Apr</td>
<td>16.2/5.9</td>
<td>0.53</td>
<td>0.80</td>
<td>1.06</td>
<td>6.1</td>
<td>12.2</td>
</tr>
<tr>
<td>10 May</td>
<td>19.6/14.5</td>
<td>0.53</td>
<td>0.80</td>
<td>1.06</td>
<td>6.1</td>
<td>12.2</td>
</tr>
<tr>
<td>24 May</td>
<td>25.5/9.2</td>
<td>0.53</td>
<td>0.80</td>
<td>1.06</td>
<td>6.1</td>
<td>12.2</td>
</tr>
<tr>
<td>7 Jun</td>
<td>28.1/12.3</td>
<td>0.53</td>
<td>0.80</td>
<td>1.06</td>
<td>6.1</td>
<td>12.2</td>
</tr>
<tr>
<td>Yearly total</td>
<td>7.32</td>
<td>11.00</td>
<td>14.64</td>
<td>24.4</td>
<td>48.8</td>
<td>97.6</td>
</tr>
<tr>
<td>2015</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 May</td>
<td>30.5/13.1</td>
<td>0.53</td>
<td>0.80</td>
<td>1.06</td>
<td>6.1</td>
<td>12.2</td>
</tr>
<tr>
<td>20 May</td>
<td>14.7/5.8</td>
<td>0.53</td>
<td>0.80</td>
<td>1.06</td>
<td>6.1</td>
<td>12.2</td>
</tr>
<tr>
<td>3 Jun</td>
<td>23.2/14.5</td>
<td>0.53</td>
<td>0.80</td>
<td>1.06</td>
<td>6.1</td>
<td>12.2</td>
</tr>
<tr>
<td>17 Jun</td>
<td>23.7/16.0</td>
<td>0.53</td>
<td>0.80</td>
<td>1.06</td>
<td>6.1</td>
<td>12.2</td>
</tr>
<tr>
<td>Yearly total</td>
<td>7.32</td>
<td>11.00</td>
<td>14.64</td>
<td>24.4</td>
<td>48.8</td>
<td>97.6</td>
</tr>
</tbody>
</table>
Table 3.3. NDVI of creeping bentgrass influenced by methiozolin rates and nitrogen rates on spring annual bluegrass control on golf greens, 2014.

| Methiozolin          | Dates          |
|----------------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| 0 kg a.i. ha\(^{-1}\) | 0 WAIT  | 2 WAIT | 4 WAIT | 6 WAIT | 8 WAIT | 10 WAIT | 12 WAIT |
| 0.545\(^{†}\)        | 0.713a       | 0.713a       | 0.763a       | 0.770a       | 0.730a       | 0.738a       |
| 0.53 kg a.i. ha\(^{-1}\) | 0.544a   | 0.708a       | 0.701b       | 0.759ab      | 0.771a       | 0.728a       | 0.741a       |
| 0.80 kg a.i. ha\(^{-1}\) | 0.530a   | 0.699ab      | 0.684c       | 0.748b       | 0.764a       | 0.727a       | 0.736ab      |
| 1.06 kg a.i. ha\(^{-1}\) | 0.525a   | 0.684b       | 0.666d       | 0.730c       | 0.757b       | 0.715b       | 0.729b       |
| Nitrogen rates       | 0.541a       | 0.690a       | 0.677a       | 0.738a       | 0.762a       | 0.722a       | 0.734a       |
| 12.2 kg N ha\(^{-1}\) | 0.535a   | 0.697a       | 0.686a       | 0.745a       | 0.763a       | 0.723a       | 0.736a       |
| 24.4 kg N ha\(^{-1}\) | 0.532a   | 0.716b       | 0.710b       | 0.766b       | 0.772b       | 0.730a       | 0.739a       |

ANOVA results

<table>
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<tr>
<th></th>
<th>Methiozolin</th>
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<th>M*N</th>
</tr>
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<td>0.0014</td>
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</table>

\(^{†}\) Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 3.4. NDVI of creeping bentgrass influenced by methiozolin rates and nitrogen rates on spring annual bluegrass control on golf greens, 2015.

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</tr>
</thead>
<tbody>
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<td>0 WAIT</td>
</tr>
<tr>
<td>0 kg a.i. ha&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>0.601a†</td>
</tr>
<tr>
<td>0.53 kg a.i. ha&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>0.612a</td>
</tr>
<tr>
<td>0.80 kg a.i. ha&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>0.614a</td>
</tr>
<tr>
<td>1.06 kg a.i. ha&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>0.635b</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>Nitrogen rates</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
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<tr>
<td>6.1 kg N ha&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>0.616a</td>
</tr>
<tr>
<td>12.2 kg N ha&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>0.618a</td>
</tr>
<tr>
<td>24.4 kg N ha&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>0.614a</td>
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</tr>
</thead>
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<tr>
<td>M*N</td>
<td>0.0385</td>
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†Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 3.5 Green Index of creeping bentgrass influenced by methiozolin rates and nitrogen rates on spring annual bluegrass control on golf greens, 2014.

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<th>4 WAIT</th>
<th>6 WAIT</th>
<th>8 WAIT</th>
<th>10 WAIT</th>
<th>12 WAIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 kg a.i. ha(^{-1})</td>
<td>5.91ab(^\dagger)</td>
<td>7.02a</td>
<td>7.01a</td>
<td>7.32a</td>
<td>7.41a</td>
<td>7.17a</td>
<td>6.89a</td>
</tr>
<tr>
<td>0.53 kg a.i. ha(^{-1})</td>
<td>5.93a</td>
<td>6.98a</td>
<td>6.93ab</td>
<td>7.30a</td>
<td>7.42a</td>
<td>7.18a</td>
<td>6.86a</td>
</tr>
<tr>
<td>0.80 kg a.i. ha(^{-1})</td>
<td>5.75b</td>
<td>6.95a</td>
<td>6.82bc</td>
<td>7.22b</td>
<td>7.38a</td>
<td>7.14a</td>
<td>6.87a</td>
</tr>
<tr>
<td>1.06 kg a.i. ha(^{-1})</td>
<td>5.75b</td>
<td>6.85b</td>
<td>6.73c</td>
<td>7.16b</td>
<td>7.32b</td>
<td>7.06b</td>
<td>6.81a</td>
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</tbody>
</table>

<table>
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<tr>
<th>Nitrogen rates</th>
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<th>4 WAIT</th>
<th>6 WAIT</th>
<th>8 WAIT</th>
<th>10 WAIT</th>
<th>12 WAIT</th>
</tr>
</thead>
<tbody>
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<td>6.1 kg N ha(^{-1})</td>
<td>5.84a</td>
<td>6.88a</td>
<td>6.80a</td>
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<td>7.35a</td>
<td>7.12a</td>
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</tr>
<tr>
<td>12.2 kg N ha(^{-1})</td>
<td>5.85a</td>
<td>6.89a</td>
<td>6.84a</td>
<td>7.24b</td>
<td>7.36a</td>
<td>7.12a</td>
<td>6.87a</td>
</tr>
<tr>
<td>24.4 kg N ha(^{-1})</td>
<td>5.82a</td>
<td>7.08b</td>
<td>6.97b</td>
<td>7.33c</td>
<td>7.43b</td>
<td>7.18b</td>
<td>6.86a</td>
</tr>
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<table>
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<tr>
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<th>Methiozolin</th>
<th>Nitrogen rates</th>
<th>M*N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methiozolin</td>
<td>0.0588</td>
<td>0.9203</td>
<td>0.3394</td>
</tr>
<tr>
<td>Nitrogen rates</td>
<td>0.017</td>
<td>&lt;0.001</td>
<td>0.0338</td>
</tr>
<tr>
<td>M*N</td>
<td>0.4145</td>
<td>0.8084</td>
<td>0.5909</td>
</tr>
</tbody>
</table>

\(^\dagger\)Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 3.6. Green Index of creeping bentgrass influenced by methiozolin rates and nitrogen rates on spring annual bluegrass control on golf greens, 2015.

<table>
<thead>
<tr>
<th>Methiozolin</th>
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<th>6 WAIT</th>
<th>8 WAIT</th>
<th>10 WAIT</th>
<th>12 WAIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 kg a.i. ha⁻¹</td>
<td>6.21a</td>
<td>7.18a</td>
<td>7.38a</td>
<td>7.37a</td>
<td>7.35a</td>
<td>7.19a</td>
<td>7.32a</td>
</tr>
<tr>
<td>0.53 kg a.i. ha⁻¹</td>
<td>6.34a</td>
<td>7.13b</td>
<td>7.37a</td>
<td>7.32a</td>
<td>7.31a</td>
<td>7.18a</td>
<td>7.31a</td>
</tr>
<tr>
<td>0.80 kg a.i. ha⁻¹</td>
<td>6.43a</td>
<td>7.13b</td>
<td>7.36a</td>
<td>7.34a</td>
<td>7.35a</td>
<td>7.15a</td>
<td>7.34a</td>
</tr>
<tr>
<td>1.06 kg a.i. ha⁻¹</td>
<td>6.42a</td>
<td>7.16ab</td>
<td>7.40a</td>
<td>7.30a</td>
<td>7.32a</td>
<td>7.18a</td>
<td>7.35a</td>
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</table>

<table>
<thead>
<tr>
<th>Nitrogen rates</th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1 kg N ha⁻¹</td>
<td>6.35a</td>
<td>7.14a</td>
<td>7.29a</td>
<td>7.31a</td>
<td>7.30a</td>
<td>7.12a</td>
<td>7.30a</td>
</tr>
<tr>
<td>12.2 kg N ha⁻¹</td>
<td>6.39a</td>
<td>7.15a</td>
<td>7.39b</td>
<td>7.34a</td>
<td>7.35a</td>
<td>7.19b</td>
<td>7.34a</td>
</tr>
<tr>
<td>24.4 kg N ha⁻¹</td>
<td>6.32a</td>
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<td>7.35a</td>
<td>7.21b</td>
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ANOVA results

<p>| | | | | | | | |</p>
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<tbody>
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<td>Methiozolin</td>
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<td>0.0973</td>
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<tr>
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<td>0.6521</td>
<td>0.2375</td>
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<td>0.9294</td>
<td>0.1007</td>
<td>0.1394</td>
<td>0.0348</td>
</tr>
</tbody>
</table>

†Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 3.7. Visual assessment of creeping bentgrass color influenced by methiozolin rates and nitrogen rates on spring annual bluegrass control on golf greens, 2014.

<table>
<thead>
<tr>
<th>Methiozolin</th>
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<th></th>
<th></th>
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<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>0 WAIT</td>
<td>2 WAIT</td>
<td>4 WAIT</td>
<td>6 WAIT</td>
<td>8 WAIT</td>
<td>10 WAIT</td>
<td>12 WAIT</td>
</tr>
<tr>
<td>0 kg a.i. ha⁻¹</td>
<td>6.0a</td>
<td>7.8a</td>
<td>7.8a</td>
<td>8.0a</td>
<td>8.3a</td>
<td>8.3a</td>
<td>7.7a</td>
</tr>
<tr>
<td>0.53 kg a.i. ha⁻¹</td>
<td>6.0a</td>
<td>7.9a</td>
<td>7.9a</td>
<td>8.4b</td>
<td>8.5b</td>
<td>8.3a</td>
<td>7.7a</td>
</tr>
<tr>
<td>0.80 kg a.i. ha⁻¹</td>
<td>6.0a</td>
<td>7.4b</td>
<td>7.6ab</td>
<td>8.3b</td>
<td>8.6b</td>
<td>8.4a</td>
<td>7.7a</td>
</tr>
<tr>
<td>1.06 kg a.i. ha⁻¹</td>
<td>6.0a</td>
<td>7.5b</td>
<td>7.3b</td>
<td>8.4b</td>
<td>8.6b</td>
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<td>7.6a</td>
</tr>
<tr>
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<td></td>
</tr>
<tr>
<td>6.1 kg N ha⁻¹</td>
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<td>7.3a</td>
<td>7.8a</td>
<td>8.3a</td>
<td>8.1a</td>
<td>7.6a</td>
</tr>
<tr>
<td>12.2 kg N ha⁻¹</td>
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<td>7.5a</td>
<td>8.3b</td>
<td>8.5b</td>
<td>8.4b</td>
<td>7.6a</td>
</tr>
<tr>
<td>24.4 kg N ha⁻¹</td>
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<td>8.2c</td>
<td>8.2b</td>
<td>8.8c</td>
<td>8.7b</td>
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<td>7.8a</td>
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</table>

ANOVA results

| Methiozolin     |            |            |            |            |            |            |            |
| Nitrogen rates  |            |            |            |            |            |            |            |
| M*N             |            |            |            |            |            |            |            |

†Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 3.8. Visual assessment of creeping bentgrass color influenced by methiozolin rates and nitrogen rates on spring annual bluegrass control on golf greens, 2015.

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<td>Methiozolin</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>6.0a†</td>
<td>7.9ab</td>
<td>8.3a</td>
<td>8.6a</td>
<td>8.7ab</td>
<td>8.1a</td>
<td>8.2a</td>
</tr>
<tr>
<td>0.53 kg a.i. ha⁻¹</td>
<td>6.0a</td>
<td>7.8a</td>
<td>8.2b</td>
<td>8.6a</td>
<td>8.5a</td>
<td>8.1a</td>
<td>8.1a</td>
</tr>
<tr>
<td>0.80 kg a.i. ha⁻¹</td>
<td>6.0a</td>
<td>7.9a</td>
<td>8.3a</td>
<td>8.5a</td>
<td>8.6ab</td>
<td>8.1a</td>
<td>8.2ab</td>
</tr>
<tr>
<td>1.06 kg a.i. ha⁻¹</td>
<td>6.0a</td>
<td>8.1b</td>
<td>8.3a</td>
<td>8.6a</td>
<td>8.7b</td>
<td>8.2a</td>
<td>8.4b</td>
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<tr>
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<td></td>
</tr>
<tr>
<td>6.1 kg N ha⁻¹</td>
<td>6.0a</td>
<td>7.7a</td>
<td>8.0a</td>
<td>8.3a</td>
<td>7.4a</td>
<td>8.0a</td>
<td>8.1a</td>
</tr>
<tr>
<td>12.2 kg N ha⁻¹</td>
<td>6.0a</td>
<td>8.0b</td>
<td>8.4b</td>
<td>8.6b</td>
<td>7.5b</td>
<td>8.0a</td>
<td>8.1a</td>
</tr>
<tr>
<td>24.4 kg N ha⁻¹</td>
<td>6.0a</td>
<td>7.1b</td>
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<td>8.8c</td>
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<td>8.4b</td>
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ANOVA results

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<th>M*N</th>
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<td>0.0074</td>
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<td>Date</td>
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<td>Date</td>
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<tr>
<td>Date</td>
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<tr>
<td>Date</td>
<td>0.0515</td>
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<td>0.7324</td>
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</tbody>
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†Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 3.9. Digital Image Analysis of creeping bentgrass color influenced by methiozolin rates and nitrogen rates on spring annual bluegrass control on golf greens, 2014.

<table>
<thead>
<tr>
<th>Nitrogen rates</th>
<th>Methiozolin</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
<tr>
<td></td>
<td>0.53 kg a.i. ha⁻¹</td>
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</tr>
<tr>
<td></td>
<td>0.80 kg a.i. ha⁻¹</td>
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</tr>
<tr>
<td></td>
<td>1.06 kg a.i. ha⁻¹</td>
<td>0.338a</td>
</tr>
<tr>
<td>6.1 kg N ha⁻¹</td>
<td>0.339a</td>
<td>0.413a</td>
</tr>
<tr>
<td>12.2 kg N ha⁻¹</td>
<td>0.334a</td>
<td>0.409a</td>
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<tr>
<td>24.4 kg N ha⁻¹</td>
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<td>0.410a</td>
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</table>

ANOVA results

<table>
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<th>Methiozolin</th>
<th>Dates</th>
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</tr>
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<td></td>
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<tr>
<td>M*N</td>
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</tbody>
</table>

†Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 3.10. Digital Image Analysis of creeping bentgrass color influenced by methiozolin rates and nitrogen rates on spring annual bluegrass control on golf greens, 2015.

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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 WAIT</td>
<td>2 WAIT</td>
<td>4 WAIT</td>
<td>6 WAIT</td>
<td>8 WAIT</td>
<td>10 WAIT</td>
<td>12 WAIT</td>
</tr>
<tr>
<td>0 kg a.i. ha⁻¹</td>
<td>0.643a†</td>
<td>0.432a</td>
<td>0.450a</td>
<td>0.419a</td>
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<tr>
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<td>0.431a</td>
<td>0.445a</td>
<td>0.413a</td>
<td>0.405a</td>
<td>0.432a</td>
<td>0.458a</td>
</tr>
<tr>
<td>0.80 kg a.i. ha⁻¹</td>
<td>0.638a</td>
<td>0.424a</td>
<td>0.454a</td>
<td>0.411a</td>
<td>0.400a</td>
<td>0.432a</td>
<td>0.458a</td>
</tr>
<tr>
<td>1.06 kg a.i. ha⁻¹</td>
<td>0.639a</td>
<td>0.426a</td>
<td>0.450a</td>
<td>0.409a</td>
<td>0.400a</td>
<td>0.438a</td>
<td>0.462a</td>
</tr>
</tbody>
</table>

| Nitrogen rates | Dates          |                |                |                |                |                |                |
|               | 0 WAIT         | 2 WAIT         | 4 WAIT         | 6 WAIT         | 8 WAIT         | 10 WAIT        | 12 WAIT        |
| 6.1 kg N ha⁻¹  | 0.640a         | 0.423a         | 0.433a         | 0.412a         | 0.398a         | 0.425a         | 0.462a         |
| 12.2 kg N ha⁻¹ | 0.640a         | 0.427a         | 0.447b         | 0.411a         | 0.399a         | 0.433a         | 0.465a         |
| 24.4 kg N ha⁻¹ | 0.638a         | 0.435a         | 0.469c         | 0.416a         | 0.407a         | 0.441a         | 0.456a         |

ANOVA results

| Methiozolin   | 0.9887         | 0.6664         | 0.6525         | 0.2459         | 0.8986         | 0.8229         | 0.5933         |
| Nitrogen rates| 0.9998         | 0.2445         | <.0001         | 0.5932         | 0.2512         | 0.1461         | 0.3087         |
| M*N           | 0.9243         | 0.1228         | 0.1370         | 0.6773         | 0.9296         | 0.4334         | 0.2911         |

†Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 3.11. NDVI of annual bluegrass influenced by methiozolin rates and nitrogen rates on spring annual bluegrass control on golf greens, 2014.

<table>
<thead>
<tr>
<th>Methiozolin</th>
<th>0 WAIT</th>
<th>2 WAIT</th>
<th>4 WAIT</th>
<th>6 WAIT</th>
<th>8 WAIT</th>
<th>10 WAIT</th>
<th>12 WAIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 kg a.i. ha⁻¹</td>
<td>0.613a</td>
<td>0.729a</td>
<td>0.707a</td>
<td>0.771a</td>
<td>0.782a</td>
<td>0.724a</td>
<td>0.749a</td>
</tr>
<tr>
<td>0.53 kg a.i. ha⁻¹</td>
<td>0.609a</td>
<td>0.681b</td>
<td>0.627b</td>
<td>0.727b</td>
<td>0.767a</td>
<td>0.728a</td>
<td>0.747a</td>
</tr>
<tr>
<td>0.80 kg a.i. ha⁻¹</td>
<td>0.601a</td>
<td>0.686bc</td>
<td>0.590b</td>
<td>0.691c</td>
<td>0.757a</td>
<td>0.723a</td>
<td>0.747a</td>
</tr>
<tr>
<td>1.06 kg a.i. ha⁻¹</td>
<td>0.597a</td>
<td>0.659c</td>
<td>0.594b</td>
<td>0.666c</td>
<td>0.668b</td>
<td>0.718a</td>
<td>0.733b</td>
</tr>
</tbody>
</table>

| Nitrogen rates | Methiozolin | 0.4916 | <.0001 | <.0001 | <.0001 | <.0001 | 0.9551 | 0.2883 |
| Nitrogen rates | Nitrogen rates | 0.5516 | 0.0009 | 0.0592 | 0.0002 | 0.3341 | 0.0987 | 0.2921 |
| M*N            | M*N         | 0.2361 | 0.0306 | 0.9403 | 0.2734 | 0.0937 | 0.5947 | 0.2812 |

†Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 3.12. NDVI of annual bluegrass influenced by methiozolin rates and nitrogen rates on spring annual bluegrass control on golf greens, 2015.

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</thead>
<tbody>
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<td>2 WAIT</td>
<td>4 WAIT</td>
<td>6 WAIT</td>
<td>8 WAIT</td>
<td>10 WAIT</td>
<td>12 WAIT</td>
</tr>
<tr>
<td>0 kg a.i. ha(^{-1})</td>
<td>0.631a†</td>
<td>0.725a</td>
<td>0.751a</td>
<td>0.766a</td>
<td>0.746a</td>
<td>0.732ab</td>
<td>0.718a</td>
<td></td>
</tr>
<tr>
<td>0.53 kg a.i. ha(^{-1})</td>
<td>0.631a</td>
<td>0.717a</td>
<td>0.748a</td>
<td>0.743a</td>
<td>0.729a</td>
<td>0.736a</td>
<td>0.727ab</td>
<td></td>
</tr>
<tr>
<td>0.80 kg a.i. ha(^{-1})</td>
<td>0.624a</td>
<td>0.717a</td>
<td>0.736a</td>
<td>0.706b</td>
<td>0.696b</td>
<td>0.733a</td>
<td>0.733b</td>
<td></td>
</tr>
<tr>
<td>1.06 kg a.i. ha(^{-1})</td>
<td>0.650a</td>
<td>0.694b</td>
<td>0.712b</td>
<td>0.692b</td>
<td>0.684b</td>
<td>0.719b</td>
<td>0.737b</td>
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<tr>
<td>Nitrogen rates</td>
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<td>0.638a</td>
<td>0.705a</td>
<td>0.724a</td>
<td>0.705a</td>
<td>0.698a</td>
<td>0.719a</td>
<td>0.722a</td>
</tr>
<tr>
<td>6.1 kg N ha(^{-1})</td>
<td>0.624a</td>
<td>0.717a</td>
<td>0.735ab</td>
<td>0.728b</td>
<td>0.716ab</td>
<td>0.731ab</td>
<td>0.732b</td>
<td></td>
</tr>
<tr>
<td>12.2 kg N ha(^{-1})</td>
<td>0.640a</td>
<td>0.717a</td>
<td>0.752b</td>
<td>0.747b</td>
<td>0.726b</td>
<td>0.740b</td>
<td>0.733b</td>
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</tr>
<tr>
<td>24.4 kg N ha(^{-1})</td>
<td>0.640a</td>
<td>0.717a</td>
<td>0.752b</td>
<td>0.747b</td>
<td>0.726b</td>
<td>0.740b</td>
<td>0.733b</td>
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ANOVA results

<table>
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<th>Nitrogen rates</th>
<th>M*N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
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<td>0.2060</td>
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<tr>
<td>2 WAIT</td>
<td>0.0332</td>
<td>0.3355</td>
<td>0.8406</td>
</tr>
<tr>
<td>4 WAIT</td>
<td>0.0030</td>
<td>0.0176</td>
<td>0.8079</td>
</tr>
<tr>
<td>6 WAIT</td>
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<td>0.0026</td>
<td>0.2182</td>
</tr>
<tr>
<td>8 WAIT</td>
<td>&lt;.0001</td>
<td>0.0235</td>
<td>0.1626</td>
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<tr>
<td>10 WAIT</td>
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<td>0.0045</td>
<td>0.2880</td>
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<td>12 WAIT</td>
<td>0.0050</td>
<td>0.0407</td>
<td>0.0068</td>
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†Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 3.13. Green Index of annual bluegrass influenced by methiozolin rates and nitrogen rates on spring annual bluegrass control on golf greens, 2014.

<table>
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<tr>
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<th>Methiozolin</th>
<th>Nitrogen rates</th>
<th>ANOVA results</th>
</tr>
</thead>
<tbody>
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<td></td>
<td>Dates</td>
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<td>2 WAIT</td>
</tr>
<tr>
<td>0 kg a.i. ha⁻¹</td>
<td>6.36a†</td>
<td>7.14a</td>
<td>6.99a</td>
</tr>
<tr>
<td>0.53 kg a.i. ha⁻¹</td>
<td>6.22a</td>
<td>6.89b</td>
<td>6.43b</td>
</tr>
<tr>
<td>0.80 kg a.i. ha⁻¹</td>
<td>6.22a</td>
<td>6.82bc</td>
<td>6.26b</td>
</tr>
<tr>
<td>1.06 kg a.i. ha⁻¹</td>
<td>6.23a</td>
<td>6.67c</td>
<td>6.17b</td>
</tr>
<tr>
<td>6.1 kg N ha⁻¹</td>
<td>6.22a</td>
<td>6.87a</td>
<td>6.46a</td>
</tr>
<tr>
<td>12.2 kg N ha⁻¹</td>
<td>6.26a</td>
<td>6.79a</td>
<td>6.43a</td>
</tr>
<tr>
<td>24.4 kg N ha⁻¹</td>
<td>6.32a</td>
<td>7.06b</td>
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ANOVA results

<table>
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<th>Methiozolin</th>
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<th>M*N</th>
</tr>
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<tbody>
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<td>0.3162</td>
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<tr>
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<tr>
<td>M*N</td>
<td>0.3162</td>
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<td>0.6491</td>
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†Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 3.14. Green Index of annual bluegrass influenced by methiozolin rates and nitrogen rates on spring annual bluegrass control on golf greens, 2015.

<table>
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<tr>
<th>Methiozolin</th>
<th>0 WAIT</th>
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<th>4 WAIT</th>
<th>6 WAIT</th>
<th>8 WAIT</th>
<th>10 WAIT</th>
<th>12 WAIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 kg a.i. ha(^{-1})</td>
<td>6.48a†</td>
<td>7.09a</td>
<td>7.40a</td>
<td>7.43a</td>
<td>7.35a</td>
<td>7.15ab</td>
<td>7.13a</td>
</tr>
<tr>
<td>0.53 kg a.i. ha(^{-1})</td>
<td>6.47a</td>
<td>7.04a</td>
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<td>7.26ab</td>
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<td>6.55a</td>
<td>7.02a</td>
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<td>7.05bc</td>
<td>7.06bc</td>
<td>7.13ab</td>
<td>7.21a</td>
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<td>1.06 kg a.i. ha(^{-1})</td>
<td>6.58a</td>
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<td>6.93c</td>
<td>7.03b</td>
<td>7.31b</td>
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<tr>
<td>Nitrogen rates</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>6.1 kg N ha(^{-1})</td>
<td>6.51a</td>
<td>6.96a</td>
<td>7.23a</td>
<td>7.03a</td>
<td>7.06a</td>
<td>7.07a</td>
<td>7.17a</td>
</tr>
<tr>
<td>12.2 kg N ha(^{-1})</td>
<td>6.50a</td>
<td>7.03a</td>
<td>7.25a</td>
<td>7.18ab</td>
<td>7.12a</td>
<td>7.09a</td>
<td>7.22a</td>
</tr>
<tr>
<td>24.4 kg N ha(^{-1})</td>
<td>6.45a</td>
<td>7.02a</td>
<td>7.29b</td>
<td>7.28b</td>
<td>7.18a</td>
<td>7.22b</td>
<td>7.21a</td>
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<tr>
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<th>Methiozolin</th>
<th>0.2555</th>
<th>0.0133</th>
<th>0.0040</th>
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<td>0.1270</td>
<td>0.8056</td>
<td>0.2614</td>
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†Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 3.15. Visual assessment of annual bluegrass color influenced by methiozolin rates and nitrogen rates on spring annual bluegrass control on golf greens, 2014.

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<tbody>
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<td></td>
<td>0 WAIT</td>
<td>2 WAIT</td>
<td>4 WAIT</td>
<td>6 WAIT</td>
<td>8 WAIT</td>
<td>10 WAIT</td>
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<td>Methiozolin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 kg a.i. ha⁻¹</td>
<td>5.5a†</td>
<td>5.6a</td>
<td>5.4a</td>
<td>5.0a</td>
<td>4.7a</td>
<td>5.6a</td>
<td>5.7a</td>
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</tr>
<tr>
<td>0.53 kg a.i. ha⁻¹</td>
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<td>5.0b</td>
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<td>3.3b</td>
<td>3.8a</td>
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<td>5.9a</td>
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</tr>
<tr>
<td>0.80 kg a.i. ha⁻¹</td>
<td>5.5a</td>
<td>4.0c</td>
<td>3.2c</td>
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<td>3.3b</td>
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<td>5.5a</td>
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<td>Nitrogen rates</td>
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</tr>
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<td>3.0a</td>
<td>4.6a</td>
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<tr>
<td>12.2 kg N ha⁻¹</td>
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<td>4.6a</td>
<td>3.5b</td>
<td>2.8a</td>
<td>2.7a</td>
<td>3.4a</td>
<td>3.8a</td>
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</tr>
<tr>
<td>24.4 kg N ha⁻¹</td>
<td>5.5a</td>
<td>4.8b</td>
<td>3.7ab</td>
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<td>3.3a</td>
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<td>4.8a</td>
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ANOVA results

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<tbody>
<tr>
<td></td>
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†Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 3.16. Visual assessment of annual bluegrass color influenced by methiozolin rates and nitrogen rates on spring annual bluegrass control on golf greens, 2015.

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<th>4 WAIT</th>
<th>6 WAIT</th>
<th>8 WAIT</th>
<th>10 WAIT</th>
<th>12 WAIT</th>
</tr>
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<tbody>
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<td>4.3ab</td>
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<td>3.8a</td>
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<td>12.2 kg N ha(^{-1})</td>
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ANOVA results

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<th>Nitrogen rates</th>
<th>M*N</th>
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<tbody>
<tr>
<td>0.0560</td>
<td>0.0031</td>
<td>0.0022</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Nitrogen rates</td>
<td>0.4917</td>
<td>0.0455</td>
<td>0.0146</td>
</tr>
<tr>
<td>M*N</td>
<td>0.1655</td>
<td>0.1925</td>
<td>0.7308</td>
</tr>
</tbody>
</table>

†Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 3.17. Digital Image Analysis of annual bluegrass color influenced by methiozolin rates and nitrogen rates on spring annual bluegrass control on golf greens, 2014.

<table>
<thead>
<tr>
<th>Methiozolin</th>
<th>0 WAIT</th>
<th>2 WAIT</th>
<th>4 WAIT</th>
<th>6 WAIT</th>
<th>8 WAIT</th>
<th>10 WAIT</th>
<th>12 WAIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 kg a.i. ha(^{-1})</td>
<td>0.472a†</td>
<td>0.493a</td>
<td>0.493a</td>
<td>0.463a</td>
<td>0.545a</td>
<td>0.540a</td>
<td>0.534a</td>
</tr>
<tr>
<td>0.53 kg a.i. ha(^{-1})</td>
<td>0.471a</td>
<td>0.470b</td>
<td>0.464b</td>
<td>0.444b</td>
<td>0.544a</td>
<td>0.554a</td>
<td>0.539a</td>
</tr>
<tr>
<td>0.80 kg a.i. ha(^{-1})</td>
<td>0.473a</td>
<td>0.456bc</td>
<td>0.439c</td>
<td>0.429c</td>
<td>0.538a</td>
<td>0.544a</td>
<td>0.531a</td>
</tr>
<tr>
<td>1.06 kg a.i. ha(^{-1})</td>
<td>0.475a</td>
<td>0.447c</td>
<td>0.429c</td>
<td>0.415c</td>
<td>0.532a</td>
<td>0.543a</td>
<td>0.535a</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nitrogen rates</th>
<th>0 WAIT</th>
<th>2 WAIT</th>
<th>4 WAIT</th>
<th>6 WAIT</th>
<th>8 WAIT</th>
<th>10 WAIT</th>
<th>12 WAIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1 kg N ha(^{-1})</td>
<td>0.472a</td>
<td>0.459a</td>
<td>0.445a</td>
<td>0.428a</td>
<td>0.534a</td>
<td>0.537a</td>
<td>0.530a</td>
</tr>
<tr>
<td>12.2 kg N ha(^{-1})</td>
<td>0.470a</td>
<td>0.468a</td>
<td>0.454ab</td>
<td>0.433a</td>
<td>0.539a</td>
<td>0.551a</td>
<td>0.535a</td>
</tr>
<tr>
<td>24.4 kg N ha(^{-1})</td>
<td>0.476a</td>
<td>0.473a</td>
<td>0.470b</td>
<td>0.452b</td>
<td>0.547a</td>
<td>0.547a</td>
<td>0.537a</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ANOVA results</th>
<th>Methiozolin</th>
<th>Nitrogen rates</th>
<th>M*N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.9246</td>
<td>0.5171</td>
<td>0.7734</td>
</tr>
<tr>
<td></td>
<td>0.0008</td>
<td>0.2972</td>
<td>0.6976</td>
</tr>
<tr>
<td></td>
<td>&lt;.0001</td>
<td>0.0334</td>
<td>0.6059</td>
</tr>
<tr>
<td></td>
<td>&lt;.0001</td>
<td>0.0022</td>
<td>0.0890</td>
</tr>
<tr>
<td></td>
<td>0.5306</td>
<td>0.2874</td>
<td>0.8900</td>
</tr>
<tr>
<td></td>
<td>0.8167</td>
<td>0.5287</td>
<td>0.8368</td>
</tr>
<tr>
<td></td>
<td>0.7555</td>
<td>0.3774</td>
<td>0.8443</td>
</tr>
</tbody>
</table>

†Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 3.18. Digital Image Analysis of annual bluegrass color influenced by methiozolin rates and nitrogen rates on spring annual bluegrass control on golf greens, 2015.

<table>
<thead>
<tr>
<th>Methiozolin</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 kg a.i. ha⁻¹</td>
<td>0 WAIT 2 WAIT 4 WAIT 6 WAIT 8 WAIT 10 WAIT 12 WAIT</td>
</tr>
<tr>
<td>0.833a†</td>
<td>0.505a 0.527a 0.516a 0.485a 0.520b 0.507a</td>
</tr>
<tr>
<td>0.53 kg a.i. ha⁻¹</td>
<td>0.801a 0.497a 0.524ab 0.503a 0.480a 0.538ab 0.521a</td>
</tr>
<tr>
<td>0.80 kg a.i. ha⁻¹</td>
<td>0.827a 0.508a 0.522ab 0.500ab 0.480a 0.548a 0.519a</td>
</tr>
<tr>
<td>1.06 kg a.i. ha⁻¹</td>
<td>0.788a 0.498a 0.515b 0.494b 0.486a 0.543a 0.518a</td>
</tr>
<tr>
<td>Nitrogen rates</td>
<td></td>
</tr>
<tr>
<td>6.1 kg N ha⁻¹</td>
<td>0.805a 0.498a 0.514b 0.507ab 0.487ab 0.542a 0.519a</td>
</tr>
<tr>
<td>12.2 kg N ha⁻¹</td>
<td>0.819a 0.508a 0.522ab 0.513a 0.490a 0.541a 0.515a</td>
</tr>
<tr>
<td>24.4 kg N ha⁻¹</td>
<td>0.813a 0.500a 0.530a 0.497b 0.472b 0.528a 0.516a</td>
</tr>
</tbody>
</table>

ANOVA results

| Methiozolin          | 0.4732 0.4810 0.2095 0.0408 0.8511 0.0455 0.7035 |
| Nitrogen rates       | 0.8912 0.3547 0.0182 0.0931 0.0797 0.2101 0.9361 |
| M*N                  | 0.3441 0.7878 0.8449 0.7908 0.4119 0.7751 0.7778 |

†Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 3.19. Changes of visual assessment of annual bluegrass population influenced by methiozolin rates and nitrogen rates on spring annual bluegrass control on golf greens, 2014.

<table>
<thead>
<tr>
<th>Methiozolin</th>
<th>Dates</th>
<th>0 WAIT</th>
<th>2 WAIT</th>
<th>4 WAIT</th>
<th>6 WAIT</th>
<th>8 WAIT</th>
<th>10 WAIT</th>
<th>12 WAIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 kg a.i. ha(^{-1})</td>
<td>(33.89%)a</td>
<td>0.56%a*</td>
<td>-1.11%a</td>
<td>2.22%a</td>
<td>5.00%a</td>
<td>3.33%a</td>
<td>3.33%a</td>
<td></td>
</tr>
<tr>
<td>0.53 kg a.i. ha(^{-1})</td>
<td>(32.78%)a</td>
<td>1.11%a</td>
<td>-0.56%a</td>
<td>-8.33%b</td>
<td>-16.11%b</td>
<td>-16.11%b</td>
<td>-19.44%b</td>
<td></td>
</tr>
<tr>
<td>0.80 kg a.i. ha(^{-1})</td>
<td>(33.89%)a</td>
<td>0.56%a</td>
<td>-1.11%a</td>
<td>-18.89%c</td>
<td>-26.22%c</td>
<td>-29.44%c</td>
<td>-28.56%c</td>
<td></td>
</tr>
<tr>
<td>1.06 kg a.i. ha(^{-1})</td>
<td>(33.89%)a</td>
<td>1.11%a</td>
<td>-5.00%a</td>
<td>-24.44%d</td>
<td>-29.11%c</td>
<td>-30.00%c</td>
<td>-31.00%c</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nitrogen rates</th>
<th>Dates</th>
<th>0 WAIT</th>
<th>2 WAIT</th>
<th>4 WAIT</th>
<th>6 WAIT</th>
<th>8 WAIT</th>
<th>10 WAIT</th>
<th>12 WAIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1 kg N ha(^{-1})</td>
<td>(32.92%)a</td>
<td>1.67%a</td>
<td>2.50%a</td>
<td>-8.75%a</td>
<td>-13.33%a</td>
<td>-17.25%a</td>
<td>-16.50%a</td>
<td></td>
</tr>
<tr>
<td>12.2 kg N ha(^{-1})</td>
<td>(34.17%)a</td>
<td>0.83%a</td>
<td>-2.92%ab</td>
<td>-15.42%b</td>
<td>-18.42%b</td>
<td>-18.00%a</td>
<td>-19.92%ab</td>
<td></td>
</tr>
<tr>
<td>24.4 kg N ha(^{-1})</td>
<td>(33.75%)a</td>
<td>0.00%a</td>
<td>-5.42%b</td>
<td>-12.92%ab</td>
<td>-18.08%b</td>
<td>-17.42%a</td>
<td>-20.33%b</td>
<td></td>
</tr>
</tbody>
</table>

ANOVA results

<table>
<thead>
<tr>
<th></th>
<th>Methiozolin</th>
<th>Nitrogen rates</th>
<th>M*N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(0.6663)</td>
<td>(0.4104)</td>
<td>(0.4946)</td>
</tr>
<tr>
<td>Methiozolin</td>
<td>0.8983</td>
<td>0.1954</td>
<td>0.5929</td>
</tr>
<tr>
<td>Nitrogen rates</td>
<td>0.4664</td>
<td>0.0221</td>
<td>0.4168</td>
</tr>
<tr>
<td>M*N</td>
<td>&lt;.0001</td>
<td>0.0190</td>
<td>0.0811</td>
</tr>
<tr>
<td></td>
<td>&lt;.0001</td>
<td>0.0476</td>
<td>0.0415</td>
</tr>
<tr>
<td></td>
<td>&lt;.0001</td>
<td>0.9484</td>
<td>0.0214</td>
</tr>
<tr>
<td></td>
<td>&lt;.0001</td>
<td>0.0800</td>
<td>0.0684</td>
</tr>
</tbody>
</table>

\*Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 3.20. Changes of visual assessment of annual bluegrass population influenced by methiozolin rates and nitrogen rates on spring annual bluegrass control on golf greens, 2015.

<table>
<thead>
<tr>
<th>Methiozolin</th>
<th>(0 WAIT)</th>
<th>2 WAIT</th>
<th>4 WAIT</th>
<th>6 WAIT</th>
<th>8 WAIT</th>
<th>10 WAIT</th>
<th>12 WAIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 kg a.i. ha(^{-1})</td>
<td>(31.67%)(a)</td>
<td>1.11%(\dagger)</td>
<td>1.67%(a)</td>
<td>2.78%(a)</td>
<td>4.44%(a)</td>
<td>3.33%(a)</td>
<td>5.00%(a)</td>
</tr>
<tr>
<td>0.53 kg a.i. ha(^{-1})</td>
<td>(32.78%)(a)</td>
<td>0.56%(a)</td>
<td>2.22%(a)</td>
<td>2.22%(a)</td>
<td>2.78%(a)</td>
<td>-8.89%(b)</td>
<td>-8.33%(b)</td>
</tr>
<tr>
<td>0.80 kg a.i. ha(^{-1})</td>
<td>(31.67%)(a)</td>
<td>0.00%(a)</td>
<td>2.78%(a)</td>
<td>3.89%(a)</td>
<td>-1.67%(b)</td>
<td>-15.56%(c)</td>
<td>-17.22%(c)</td>
</tr>
<tr>
<td>1.06 kg a.i. ha(^{-1})</td>
<td>(32.22%)(a)</td>
<td>0.56%(a)</td>
<td>4.44%(a)</td>
<td>1.67%(a)</td>
<td>-3.89%(b)</td>
<td>-22.78%(d)</td>
<td>-22.78%(d)</td>
</tr>
<tr>
<td>Nitrogen rates</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.1 kg N ha(^{-1})</td>
<td>(32.08%)(a)</td>
<td>0.83%(a)</td>
<td>3.33%(a)</td>
<td>2.92%(a)</td>
<td>0.00%(a)</td>
<td>-10.83%(a)</td>
<td>-11.25%(a)</td>
</tr>
<tr>
<td>12.2 kg N ha(^{-1})</td>
<td>(32.50%)(a)</td>
<td>0.42%(a)</td>
<td>2.92%(a)</td>
<td>2.92%(a)</td>
<td>0.83%(a)</td>
<td>-10.83%(a)</td>
<td>-10.42%(a)</td>
</tr>
<tr>
<td>24.4 kg N ha(^{-1})</td>
<td>(31.67%)(a)</td>
<td>0.42%(a)</td>
<td>2.08%(a)</td>
<td>2.08%(a)</td>
<td>0.42%(a)</td>
<td>-11.25%(a)</td>
<td>-10.83%(a)</td>
</tr>
</tbody>
</table>

ANOVA results

<table>
<thead>
<tr>
<th>Methiozolin</th>
<th>(0.7106)</th>
<th>0.4491</th>
<th>0.2757</th>
<th>0.5087</th>
<th>&lt;.0001</th>
<th>&lt;.0001</th>
<th>&lt;.0001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen rates</td>
<td>(0.6887)</td>
<td>0.7128</td>
<td>0.6035</td>
<td>0.7634</td>
<td>0.8259</td>
<td>0.9621</td>
<td>0.8337</td>
</tr>
<tr>
<td>M*N</td>
<td>(0.1615)</td>
<td>0.3153</td>
<td>0.6425</td>
<td>0.4488</td>
<td>0.6469</td>
<td>0.7222</td>
<td>0.2033</td>
</tr>
</tbody>
</table>

\(\dagger\) Means followed by the same letter are not significantly different (\(P \leq 0.05\)) according to the Fisher’s least significant difference (LSD) test.
Table 3.21. Changes of grid counting of annual bluegrass population influenced by methiozolin rates and nitrogen rates on spring annual bluegrass control on golf greens, 2014.

<table>
<thead>
<tr>
<th></th>
<th>Dates</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(0 WAIT)</td>
<td>4 WAIT</td>
<td>8 WAIT</td>
<td>12 WAIT</td>
</tr>
<tr>
<td>Methiozolin 0 kg a.i. ha⁻¹</td>
<td>21.53%</td>
<td>-2.11%a†</td>
<td>-1.97%a</td>
<td>-3.26%a</td>
</tr>
<tr>
<td>Methiozolin 0.53 kg a.i. ha⁻¹</td>
<td>20.02%</td>
<td>-6.15%b</td>
<td>-10.56%b</td>
<td>-11.76%b</td>
</tr>
<tr>
<td>Methiozolin 0.80 kg a.i. ha⁻¹</td>
<td>21.21%</td>
<td>-5.83%b</td>
<td>-16.39%c</td>
<td>-16.67%c</td>
</tr>
<tr>
<td>Methiozolin 1.06 kg a.i. ha⁻¹</td>
<td>22.45%</td>
<td>-8.08%b</td>
<td>-19.28%c</td>
<td>-19.51%d</td>
</tr>
<tr>
<td>Nitrogen rates 6.1 kg N ha⁻¹</td>
<td>21.38%</td>
<td>-4.65%a</td>
<td>-12.12%ab</td>
<td>-12.89%ab</td>
</tr>
<tr>
<td>Nitrogen rates 12.2 kg N ha⁻¹</td>
<td>18.94%</td>
<td>-4.61%a</td>
<td>-10.30%a</td>
<td>-11.33%a</td>
</tr>
<tr>
<td>Nitrogen rates 24.4 kg N ha⁻¹</td>
<td>23.59%</td>
<td>-7.37%b</td>
<td>-13.74%b</td>
<td>-14.19%b</td>
</tr>
</tbody>
</table>

ANOVA results

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Methiozolin</td>
<td>0.7121</td>
<td>0.0030</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Nitrogen rates</td>
<td>0.0561</td>
<td>0.0529</td>
<td>0.0504</td>
<td>0.0406</td>
</tr>
<tr>
<td>M*N</td>
<td>0.5717</td>
<td>0.0279</td>
<td>0.0206</td>
<td>0.0258</td>
</tr>
</tbody>
</table>

† Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 3.22. Changes of grid counting of annual bluegrass population influenced by methiozolin rates and nitrogen rates on spring annual bluegrass control on golf greens, 2015.

<table>
<thead>
<tr>
<th>Dates</th>
<th>Methiozolin</th>
<th>Nitrogen rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>(0 WAIT)</td>
<td>0 kg a.i. ha(^{-1})</td>
<td>6.1 kg N ha(^{-1})</td>
</tr>
<tr>
<td></td>
<td>(25.57%)</td>
<td>(26.89%)</td>
</tr>
<tr>
<td>4 WAIT</td>
<td>0.53 kg a.i. ha(^{-1})</td>
<td>12.2 kg N ha(^{-1})</td>
</tr>
<tr>
<td></td>
<td>(27.64%)</td>
<td>(25.93%)</td>
</tr>
<tr>
<td>8 WAIT</td>
<td>0.80 kg a.i. ha(^{-1})</td>
<td>24.4 kg N ha(^{-1})</td>
</tr>
<tr>
<td></td>
<td>(25.25%)</td>
<td>(27.96%)</td>
</tr>
<tr>
<td>12 WAIT</td>
<td>1.06 kg a.i. ha(^{-1})</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(29.25%)</td>
<td></td>
</tr>
</tbody>
</table>

|         | (0.2724)    | (0.5869)       |
| ANOVA results |
| Methiozolin |
| Nitrogen rates |
| M*N         |

†Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 3.23. Changes of Digital Image Analysis of annual bluegrass population influenced by methiozolin rates and nitrogen rates on spring annual bluegrass control on golf greens, 2014.

<table>
<thead>
<tr>
<th>Methiozolin</th>
<th>Dates</th>
<th>2 WAIT</th>
<th>4 WAIT</th>
<th>6 WAIT</th>
<th>8 WAIT</th>
<th>10 WAIT</th>
<th>12 WAIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 kg a.i. ha⁻¹</td>
<td>0.1984</td>
<td>0.4491</td>
<td>0.8483</td>
<td>0.1187</td>
<td>0.1403</td>
<td>0.0694</td>
<td></td>
</tr>
<tr>
<td>0.53 kg a.i. ha⁻¹</td>
<td>0.0734</td>
<td>0.4926</td>
<td>0.0754</td>
<td>0.5191</td>
<td>0.4445</td>
<td>0.2636</td>
<td></td>
</tr>
<tr>
<td>0.80 kg a.i. ha⁻¹</td>
<td>0.2690</td>
<td>0.7208</td>
<td>0.0381</td>
<td>0.6589</td>
<td>0.6180</td>
<td>0.7132</td>
<td></td>
</tr>
<tr>
<td>1.06 kg a.i. ha⁻¹</td>
<td>0.0734</td>
<td>0.4926</td>
<td>0.0754</td>
<td>0.5191</td>
<td>0.4445</td>
<td>0.2636</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nitrogen rates</th>
<th>Dates</th>
<th>2 WAIT</th>
<th>4 WAIT</th>
<th>6 WAIT</th>
<th>8 WAIT</th>
<th>10 WAIT</th>
<th>12 WAIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1 kg N ha⁻¹</td>
<td>4939a</td>
<td>-2931a</td>
<td>582a</td>
<td>9775a</td>
<td>-2300a</td>
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</tr>
<tr>
<td>12.2 kg N ha⁻¹</td>
<td>-1726ab</td>
<td>-3611a</td>
<td>-2468ab</td>
<td>6249a</td>
<td>-3614a</td>
<td>-8090a</td>
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<tr>
<td>24.4 kg N ha⁻¹</td>
<td>-4606b</td>
<td>-7190a</td>
<td>-8612b</td>
<td>183a</td>
<td>-9047a</td>
<td>-15047a</td>
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ANOVA results

<table>
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<tr>
<th>Methiozolin</th>
<th>Nitrogen rates</th>
<th>M*N</th>
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<tr>
<td>0.1984</td>
<td>0.0491</td>
<td>0.0843</td>
</tr>
<tr>
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<td>0.04926</td>
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<td>0.2690</td>
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†Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 3.24. Changes of Digital Image Analysis of annual bluegrass population influenced by methiozolin rates and nitrogen rates on spring annual bluegrass control on golf greens, 2015.

<table>
<thead>
<tr>
<th>Methiozolin</th>
<th>2 WAIT</th>
<th>4 WAIT</th>
<th>6 WAIT</th>
<th>8 WAIT</th>
<th>10 WAIT</th>
<th>12 WAIT</th>
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<tr>
<td>0 kg a.i. ha(^{-1})</td>
<td>32877a†</td>
<td>12433a</td>
<td>-5602a</td>
<td>835a</td>
<td>7042a</td>
<td>41397a</td>
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<tr>
<td>0.53 kg a.i. ha(^{-1})</td>
<td>28730a</td>
<td>10587a</td>
<td>-1438a</td>
<td>4579a</td>
<td>-7229ab</td>
<td>22846a</td>
</tr>
<tr>
<td>0.80 kg a.i. ha(^{-1})</td>
<td>20603a</td>
<td>17557a</td>
<td>6101a</td>
<td>-1577a</td>
<td>-8894ab</td>
<td>41670a</td>
</tr>
<tr>
<td>1.06 kg a.i. ha(^{-1})</td>
<td>17683a</td>
<td>14894a</td>
<td>3961a</td>
<td>-9862a</td>
<td>-13589b</td>
<td>37151a</td>
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<tr>
<td>Nitrogen rates</td>
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<td></td>
</tr>
<tr>
<td>6.1 kg N ha(^{-1})</td>
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<td>10708a</td>
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<td>24.4 kg N ha(^{-1})</td>
<td>30630a</td>
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<table>
<thead>
<tr>
<th>ANOVA results</th>
<th>Methiozolin</th>
<th>Nitrogen rates</th>
<th>M*N</th>
</tr>
</thead>
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<td>0.5691</td>
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<td>0.0964</td>
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<td></td>
<td>0.2406</td>
<td>0.3993</td>
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<td></td>
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<td>0.1038</td>
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<td>0.3076</td>
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<tr>
<td></td>
<td>0.9146</td>
<td>0.5259</td>
<td>0.4218</td>
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</tbody>
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†Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Figure 3.1. The effect of methiozolin rates on the NDVI of creeping bentgrass 2, 4, 6, 8, 10, and 12 weeks after initial treatment in a) 2014 and b) 2015.

1 Means followed by the same letter are not significantly different ($P \leq 0.05$) according to the Fisher’s least significant difference (LSD) test.

2 Methiozolin treatments: $M_0 = 0$ kg a.i. ha$^{-1}$, $M_1 = 0.53$ kg a.i. ha$^{-1}$, $M_2 = 0.80$ kg a.i. ha$^{-1}$, $M_3 = 1.06$ kg a.i. ha$^{-1}$.
Figure 3.2. The effect of nitrogen rates on the NDVI of creeping bentgrass 2, 4, 6, 8, 10, and 12 weeks after initial treatment in a) 2014 and b) 2015.

1 Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.

2 Nitrogen treatments: N1 = 6.1 kg N ha⁻¹, N2 = 12.2 kg N ha⁻¹, N4 = 24.4 kg N ha⁻¹.
Figure 3.3. The effect of methiozolin rates on the Green Index of creeping bentgrass 2, 4, 6, 8, 10, and 12 weeks after initial treatment in a) 2014 and b) 2015.

1 Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.

2 Methiozolin treatments: M0 = 0 kg a.i. ha\(^{-1}\), M1 = 0.53 kg a.i. ha\(^{-1}\), M2 = 0.80 kg a.i. ha\(^{-1}\), M3 = 1.06 kg a.i. ha\(^{-1}\).
Figure 3.4. The effect of nitrogen rates on the Green Index of creeping bentgrass 2, 4, 6, 8, 10, and 12 weeks after initial treatment in a) 2014 and b) 2015.

1 Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.

2 Nitrogen treatments: N1 = 6.1 kg N ha⁻¹, N2 = 12.2 kg N ha⁻¹, N4 = 24.4 kg N ha⁻¹.
Figure 3.5. The effect of methiozolin rates on the visual assessment score of creeping bentgrass 2, 4, 6, 8, 10, and 12 weeks after initial treatment in a) 2014 and b) 2015.

1 Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
2 Methiozolin treatments: M0 = 0 kg a.i. ha\(^{-1}\), M1 = 0.53 kg a.i. ha\(^{-1}\), M2 = 0.80 kg a.i. ha\(^{-1}\), M3 = 1.06 kg a.i. ha\(^{-1}\).
Figure 3.6. The effect of nitrogen rates on the visual assessment score of creeping bentgrass 2, 4, 6, 8, 10, and 12 weeks after initial treatment in a) 2014 and b) 2015.

1 Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.

2 Nitrogen treatments: N1 = 6.1 kg N ha\(^{-1}\), N2 = 12.2 kg N ha\(^{-1}\), N4 = 24.4 kg N ha\(^{-1}\).
Figure 3.7. The effect of methiozolin rates on the digital image analysis of creeping bentgrass 2, 4, 6, 8, 10, and 12 weeks after initial treatment in a) 2014 and b) 2015.

1 Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.

2 Methiozolin treatments: M0 = 0 kg a.i. ha⁻¹, M1 = 0.53 kg a.i. ha⁻¹, M2 = 0.80 kg a.i. ha⁻¹, M3 = 1.06 kg a.i. ha⁻¹.
Figure 3.8. The effect of nitrogen rates on the digital image analysis of creeping bentgrass 2, 4, 6, 8, 10, and 12 weeks after initial treatment in a) 2014 and b) 2015.

1 Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
2 Nitrogen treatments: N1 = 6.1 kg N ha⁻¹, N2 = 12.2 kg N ha⁻¹, N4 = 24.4 kg N ha⁻¹.
Figure 3.9. The effect of methiozolin rates on the NDVI of annual bluegrass 2, 4, 6, 8, 10, and 12 weeks after initial treatment in a) 2014 and b) 2015.

1 Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.

2 Methiozolin treatments: M0 = 0 kg a.i. ha⁻¹, M1 = 0.53 kg a.i. ha⁻¹, M2 = 0.80 kg a.i. ha⁻¹, M3 = 1.06 kg a.i. ha⁻¹.
Figure 3.10. The effect of nitrogen rates on the NDVI of annual bluegrass 2, 4, 6, 8, 10, and 12 weeks after initial treatment in a) 2014 and b) 2015.

1 Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.

2 Nitrogen treatments: N1 = 6.1 kg N ha⁻¹, N2 = 12.2 kg N ha⁻¹, N4 = 24.4 kg N ha⁻¹.
Figure 3.11. The effect of methiozolin rates on the Green Index of annual bluegrass 2, 4, 6, 8, 10, and 12 weeks after initial treatment in a) 2014 and b) 2015.

1 Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.

2 Methiozolin treatments: M0 = 0 kg a.i. ha⁻¹, M1 = 0.53 kg a.i. ha⁻¹, M2 = 0.80 kg a.i. ha⁻¹, M3 = 1.06 kg a.i. ha⁻¹.
Figure 3.12. The effect of nitrogen rates on the Green Index of annual bluegrass 2, 4, 6, 8, 10, and 12 weeks after initial treatment in a) 2014 and b) 2015.

1 Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.

2 Nitrogen treatments: N1 = 6.1 kg N ha⁻¹, N2 = 12.2 kg N ha⁻¹, N4 = 24.4 kg N ha⁻¹.
Figure 3.13. The effect of methiozolin rates on the visual assessment score of annual bluegrass 2, 4, 6, 8, 10, and 12 weeks after initial treatment in a) 2014 and b) 2015.

1 Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.

2 Methiozolin treatments: M0 = 0 kg a.i. ha⁻¹, M1 = 0.53 kg a.i. ha⁻¹, M2 = 0.80 kg a.i. ha⁻¹, M3 = 1.06 kg a.i. ha⁻¹.
Figure 3.14. The effect of nitrogen rates on the visual assessment score of annual bluegrass 2, 4, 6, 8, 10, and 12 weeks after initial treatment in a) 2014 and b) 2015.

1 Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.

2 Nitrogen treatments: N1 = 6.1 kg N ha⁻¹, N2 = 12.2 kg N ha⁻¹, N4 = 24.4 kg N ha⁻¹.
Figure 3.15. The effect of methiozolin rates on the digital image analysis of annual bluegrass 2, 4, 6, 8, 10, and 12 weeks after initial treatment in a) 2014 and b) 2015.

1 Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.

Methiozolin treatments: M0 = 0 kg a.i. ha\(^{-1}\), M1 = 0.53 kg a.i. ha\(^{-1}\), M2 = 0.80 kg a.i. ha\(^{-1}\), M3 = 1.06 kg a.i. ha\(^{-1}\).
Figure 3.16. The effect of nitrogen rates on the digital image analysis of annual bluegrass 2, 4, 6, 8, 10, and 12 weeks after initial treatment in a) 2014 and b) 2015.

1 Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.

2 Nitrogen treatments: N1 = 6.1 kg N ha⁻¹, N2 = 12.2 kg N ha⁻¹, N4 = 24.4 kg N ha⁻¹.
Figure 3.17. The effect of methiozolin rates on the change of visual assessment of annual bluegrass population 2, 4, 6, 8, 10, and 12 weeks after initial treatment in a) 2014 and b) 2015.

1 Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
2 Methiozolin treatments: M0 = 0 kg a.i. ha⁻¹, M1 = 0.53 kg a.i. ha⁻¹, M2 = 0.80 kg a.i. ha⁻¹, M3 = 1.06 kg a.i. ha⁻¹.
Figure 3.18. The effect of nitrogen rates on the change of visual assessment of annual bluegrass population 2, 4, 6, 8, 10, and 12 weeks after initial treatment in a) 2014 and b) 2015.

1 Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.

2 Nitrogen treatments: N1 = 6.1 kg N ha⁻¹, N2 = 12.2 kg N ha⁻¹, N4 = 24.4 kg N ha⁻¹.
Figure 3.19. The effect of methiozolin rates on the change of grid counting annual bluegrass population 2, 4, 6, 8, 10, and 12 weeks after initial treatment in a) 2014 and b) 2015.

1 Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.

2 Methiozolin treatments: M0 = 0 kg a.i. ha⁻¹, M1 = 0.53 kg a.i. ha⁻¹, M2 = 0.80 kg a.i. ha⁻¹, M3 = 1.06 kg a.i. ha⁻¹.
Figure 3.20. The effect of nitrogen rates on the change of grid counting annual bluegrass population 2, 4, 6, 8, 10, and 12 weeks after initial treatment in a) 2014 and b) 2015.

1 Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.

2 Nitrogen treatments: N1 = 6.1 kg N ha\(^{-1}\), N2 = 12.2 kg N ha\(^{-1}\), N4 = 24.4 kg N ha\(^{-1}\).
Chapter 4: The Effects of Nitrogen Rates and Methiozolin on Creeping Bentgrass Lateral Growth

Introduction

Nitrogen as the main component of protein, is the fourth most abundant element in plants after carbon, hydrogen and oxygen. Nitrogen plays an important role in the lateral growth and chlorophyll formation of the plant, which can greatly influence the recovery rate, color and stress tolerance of turfgrass (Schlossberg and Schmidt, 2007; Beard, 1973; Turner and Hummel, 1992) of turfgrass. It is the most applied macronutrient in the turfgrass fertilization program along with phosphorus and potassium. Methiozolin is a newly developed selective herbicide for annual bluegrass control which has shown its safety on creeping bentgrass, perennial ryegrass, tall fescue, and bermudagrass. Koo et al. (2013) found that even though this chemical is safe on untargeted species, it still has some PGR effects on turfgrass species. These effects include reduction of clipping yield, a decrease in color and inhibition of seed head production. Since methiozolin has the opposite effects on turfgrass growth compared with nitrogen, it would be valuable to study how these two chemicals interact together on the health (color/quality, lateral growth, etc.) of an untargeted grass species, like creeping bentgrass. However, to date, there has been no research studying the interaction between methiozolin and nitrogen rates on the color and lateral growth of creeping bentgrass.
The objectives of this project were 1) to determine the effects of methiozolin and five nitrogen rates on the surface quality of creeping bentgrass; 2) to determine the effects of methiozolin and five nitrogen rates on the lateral growth rate of creeping bentgrass; 3) to find the color/quality and lateral growth rate of creeping bentgrass under any nitrogen rates by regression.

Material and Methods
A two-year field study was conducted from April, 2014 to July, 2015 on the USGA research green at the Ohio State University Turfgrass Research and Education Facility, located in Columbus, Ohio. The study was established on an “A4” creeping bentgrass USGA green. According to the soil test, the soil pH on this green was 7.2. The available macronutrient in the soil, including phosphorus, potassium, calcium and magnesium, were 36.96 kg ha\(^{-1}\), 128.80 kg ha\(^{-1}\), 3,345.44 kg ha\(^{-1}\) and 280.00 kg ha\(^{-1}\), respectively. The available micronutrient in the soil, including iron, manganese, zinc and copper, were 52.64 kg ha\(^{-1}\), 10.08 kg ha\(^{-1}\), 5.26 kg ha\(^{-1}\) and 3.58 kg ha\(^{-1}\), respectively. The micronutrients were sufficient for creeping bentgrass growth.

The area was functioning as a putting green for research purposes, and maintained as a regular golf green. The green was mowed daily at the height of 3.2 mm with a walk-behind reel mower. All the fertilizer and PGR applications were skipped on this green, since nitrogen rate was one of the treatments and methiozolin is considered to have PGR effects. A total of 0.3 kg ha\(^{-1}\) of Carfentrazone-ethyl (Quicksilver, FMC Corporation, Philadelphia, PA) was applied for moss control. Deltamethrin \(((s)-\alpha\text{-cyano-3-phenoxy-benzyl-(1R, 3R)-3-(2,2-dibromovinyl)-2,2-dimethylcyclopropanecarboxylate})\)
(DeltaGard GC, Bayer Environmental Science, Montvale, NJ) was applied at the rate of 0.087 kg a.i. ha\(^{-1}\) for ant control. For dollar spot control, 2.84 kg a.i. ha\(^{-1}\) of iprodione [3-(3,5-dichlorophenyl)-N-(1-methylethyl)-2,4-dioxo-1-imidazolidinecarboxamide] (26GT, Bayer Environmental Science, Research Triangle Park, NC); 14.41 kg a.i. ha\(^{-1}\) of chlorothalonil (tetrachloroisophthalonitrile) (Daconil Weatherstik, Syngenta Crop Protection, LLC, Greensboro, NC); 0.44 kg a.i. ha\(^{-1}\) of propiconazole (Procon-Z, Loveland Products Inc, Greeley, CO); 4.93 kg a.i. ha\(^{-1}\) of thiophanate-methyl (T-Methyl SPC 4.5 F, Nufarm Americas Inc., Burr Ridge, IL) was applied during the experimental period.

A 2 \times 5 factorial experiment was set up as a random complete block design with three replications. Two levels of methiozolin rate (0, and 0.53 kg a.i. ha\(^{-1}\)) and five levels of nitrogen rate (0, 3.05, 6.1, 12.2, and 24.4 kg N ha\(^{-1}\)) were randomized jointly within each block. All the treatments are shown in Table 4.1. The size of the plot was 1.5 by 0.91 m. There was 0.15 m border space between the plots along the long side and 0.3 m border space between the plots along the short side. The whole experiment area was 10.36 by 5.18 m. In the second year (spring 2015), the whole experiment was repeated with the same design and laid out in another USGA research green adjacent to the first one at OSU turf research and education facility. All the treatments were re-randomized in the repeated experiment.

In the field preparation stage, two holes were cut with a 0.1 m golf green cup cutter from the green and filled back with sand. The lateral growth rate of creeping bentgrass was studied by monitoring the size change of the sand hole.
The initial application of spring methiozolin treatments and nitrogen treatments was started on April 23 in 2014 and May 4 in 2015. All the treatments of methiozolin and nitrogen were applied at a two-week intervals. The application dates of methiozolin and nitrogen are as listed in Table 4.2. Ammonium sulfate (S’Sul, American Plant Food Corp., Galena Park, TX) was used as the N-source. All treatments were sprayed with a CO₂ backpack sprayer (300 kPa) equipped with a Tjn_TP6503 (Teejet, Wheaton, IL) flat fan nozzle, which was calibrated to deliver 845.88 L liquid per hectare.

Initial baseline data was taken before the first treatment application in each year and all the data was collected every two weeks after the initial treatment (WAIT). The measurements focused mainly on two aspects: color/quality of the creeping bentgrass and the size of the sand hole. The measurement methods for turf surface color/quality included visual assessment, normalized difference vegetation index (NDVI), dark green color index (DGCI) and digital image analysis (DIA). The measurement methods for the size of the sand hole included grid counting and digital image analysis (DIA).

Visual assessment of creeping bentgrass color/quality was rated according to the guide to NTEP guide for turfgrass color/quality rating procedure. Creeping bentgrass spring green-up color/quality was rated based on a 1 to 9 scale, with 1 being entirely straw brown; 6 being minimum acceptance of color by a golf course superintendent; and 9 being completely dark green color. The same person took all the visual assessments every two weeks over the two year experimental period.

Normalized difference vegetation index first raised by Rouse et al. (1973) is a function of visible red reflectance (VIS) and near-infrared reflectance (NIR).
Many scientists have utilized NDVI as a method to evaluate turfgrass canopy characteristics, especially the turfgrass color (Trenholm et al., 1999; Jiang et al., 2003; Xiong et al., 2007; Sönmez et al., 2008). NDVI was taken with a TCM 500 NDVI turf color meter (FieldScout, Spectrum Technologies, Inc., Aurora, IL). The NDVI turf color meter has a light chamber with internal light source to negate the interference from external light. The measurement area consisted of a 7.6 cm diameter circular opening on the bottom of the light chamber. Three subsamples were randomly measured in each plot to take creeping bentgrass NDVI data. After all, the average of the subsamples was utilized as the NDVI value of each plot. NDVI data was taken every two weeks concurrent with visual assessments.

Dark green color index was taken with the customized Green Index function of the TCM 500 NDVI turf color meter. The Green Index was first set at the beginning of the experiment in the spring 2014. A 6 score was taken as the minimum acceptable color and the setting was not changed throughout the two year experimental period. The turf color meter offers Green Index readings according to the same standard and gives Green Index readings from 1 to 9. As with NDVI data, three subsamples were randomly assigned in each plot to take creeping bentgrass DGCI data. After all, the average of the subsamples was utilized as the DGCI value of each plot. Green Index data was taken every two weeks.

Grid counting was performed to offer an objective presentation of the size changes of the sand hole in the creeping bentgrass green. The grid is 0.15 by 0.15 m with
a total of 225 intersections at a 9.5 by 9.5 mm spacing. During the counting process, any absence of creeping bentgrass living tissue at the intersection point was considered a positive count. The total positive counts of the absence of creeping bentgrass were taken as the size of the sand hole. The grid counting was performed by the same person throughout two-year experimental period and was conducted before the initial treatments were applied and every two weeks after the initial treatments.

Digital image analysis is a new method for turfgrass surface quality evaluation. Richardson et al. (2001) has found that digital image analysis has lowered the mean variance of percent coverage of bermudagrass from 99.12 using visual assessment and 13.18 using the grid counting method to 0.65, which means digital image analysis is more accurate and objective in determination of turfgrass coverage. A 0.5 by 0.6 m light photo box (Digital analysis light box assembly, NexGen Turf Research, Albany, Oregon) and a digital camera (Sony SLT-A57, SAL1855 lens, Sony Corp.) were utilized to take one photo from each plot every two weeks. One portable power source (Powerpack 600, Duracell, Bethel, CT) was attached to the light box to power four compact fluorescent bulbs with 63662 cd as a constant light source in the box. The camera was set at manual model and a 3568 × 2368 digital image was taken with 1/10 second exposure time and 800 ISO Sensitivity. Photos were saved into Joint Photographic Experts Group (JPG) format, loaded into a personal computer and analyzed with ImageJ (ImageJ, U. S. National Institutes of Health, Bethesda, MD). The red, green and blue (RGB) levels were exported and converted into Hue, Saturation and Brightness (HSB) parameters. The HSB values would be used in the Dark Green Color Index (DGCI) for turfgrass color analysis.
The size of the sand holes in each plot is also measured by counting the pixel numbers in sand color with ImageJ.

Analysis of all the data was performed with SAS 9.3 (SAS Institute Inc., Cary, NC) and Microsoft Excel (Microsoft Office Professional Plus 2013). ODS Graphics was used for the test of the assumptions of ANOVA and PROC GLM was utilized in SAS for ANOVA test. Fisher’s protected least significant difference (LSD) values for mean comparisons (p ≤ 0.05). Significant interactions were detected between years and the treatments; thus, data from each year were analyzed and discussed separately.

Results

*Creeping Bentgrass Color/Quality*

Creeping bentgrass color/quality was measured with NDVI, green index, visual assessment and the Digital Image Analysis methods to study the effects of spring methiozolin applications and nitrogen rates on the surface quality and the rate of lateral growth/recovery of a creeping bentgrass putting green. Overall, the color ratings showed no significant differences between methiozolin treatment rates and no methiozolin treatments. There was significant effects (p <.0001) of nitrogen rates on the color of creeping bentgrass from two WAIT in 2014 and four WAIT 2015. There was also a lack of significant interactions between methiozolin and nitrogen rates most rating dates during the two-year experiment period.

Table 4.3 shows the NDVI of creeping bentgrass affected by methiozolin rates and nitrogen rates in 2014. As shown in the ANOVA results, there was no significant difference between plots before any application of methiozolin and nitrogen. Even though
methiozolin treatments had lower NDVI ratings than no methiozolin treatments, the differences were not statistically significant except eight WAIT (p = 0.0466, June 15, 2014). The NDVI of creeping bentgrass was mainly caused by nitrogen rates, which has a significant level below 0.0001 from two WAIT to the twelve WAIT. Except at six WAIT (p = 0.0367, June 3, 2014). There were no significant interactions between methiozolin and nitrogen rates. The NDVI of creeping bentgrass under different methiozolin and nitrogen rate treatments in 2015 are similar to the results from 2014 (Table 4.4). No significant difference was observed between the methiozolin and no methiozolin treatments, even though the NDVI of creeping bentgrass with methiozolin was lower than no methiozolin treatment throughout the entire experimental period in 2015. The significant effects (p ≤ 0.05) of nitrogen rates on the NDVI of creeping bentgrass occurred later and also lasted for a shorter period of time in 2015 than in 2014. The nitrogen rate treatments resulted in a significant difference on the NDVI of creeping bentgrass starting at four WAIT (p < .0001) and ending at ten WAIT (p = 0.0005). There were no significant differences among nitrogen rates twelve WAIT, which is also six weeks after the last application of nitrogen. Also, no significant interaction were determined during the experimental period in 2015.

Figure 4.1 shows the effect of nitrogen rates on the NDVI of creeping bentgrass in both 2014 and 2015. As with the ANOVA results in Table 4.3, there were significant differences among nitrogen rates after only one application in 2014. At two WAIT, the NDVI of creeping bentgrass increased with higher nitrogen rates. Among all the nitrogen rates, the 6.1 kg N ha\(^{-1}\), the 12.2 kg N ha\(^{-1}\), and the 24.4 kg N ha\(^{-1}\) had significantly higher NDVI ratings than the no nitrogen treatment. There was no significant difference
between the 12.2 kg N ha\(^{-1}\) and the 24.4 kg N ha\(^{-1}\) at two WAIT. From four WAIT to eight WAIT, all nitrogen treatments had a significantly higher creeping bentgrass NDVI than the no nitrogen treatment and from six WAIT to eight WAIT all the nitrogen rates were significantly different from each other. From ten WAIT to twelve WAIT, the NDVI of creeping bentgrass still increased significantly with higher nitrogen rates, however the difference was relatively smaller than at six and eight WAIT. Another observation was that in 2014 in Figure 4.1 (a) was that the creeping bentgrass NDVI of the no nitrogen treatment and the 3.05 kg N ha\(^{-1}\) continued to increase during the experiment period. The NDVI of creeping bentgrass under higher nitrogen rates all reached a peak around eight to ten WAIT then started to decrease. Even with this decrease in color, the higher nitrogen treatments still had higher NDVI ratings than the lower nitrogen treatments.

Unlike 2014, the nitrogen treatments started to show significant effects on the NDVI of creeping bentgrass at four WAIT instead of two WAIT in 2015 [Figure 4.1(b)]. Also, in 2015 the lowest nitrogen rate, 3.05 kg ha\(^{-1}\), was not significantly different from the no nitrogen treatment. All the other higher nitrogen treatments had a higher NDVI rating than the no nitrogen treatment from four WAIT to ten WAIT. The 12.2 kg N ha\(^{-1}\) and the 24.4 kg N ha\(^{-1}\) were significantly higher than 6.1 kg N ha\(^{-1}\) from four WAIT to six WAIT. The 24.4 kg N ha\(^{-1}\) was significantly higher than the 12.2 kg N ha\(^{-1}\) only at six WAIT. At twelve WAIT, which is also six weeks after the last application of nitrogen, there were essentially no significant differences among nitrogen rates on the NDVI of creeping bentgrass. This was probably due to the warmer weather in the spring of 2015 resulting in a faster green up of creeping bentgrass and more sensitivity to chemical stress caused by high nitrogen programs. Table 4.5 and Table 4.6 show the ANOVA results.
of the green index of creeping bentgrass under difference methiozolin treatments and nitrogen treatments in 2014 and 2015, respectively. Lacking the initial data before the first application, the green index measurements of creeping bentgrass started at two WAIT in 2014 (Table 4.5). Very similar to the NDVI data, there were no significant differences between methiozolin and the no methiozolin treatments. There were also no significant interactions between factors. There was a significant difference among nitrogen rates starting from two WAIT in 2014 and from four WAIT in 2015 to the end of the experimental period in both years.

Figure 4.2 shows the green index of creeping bentgrass affected by nitrogen rates in 2014 and 2015. In general, the effects of nitrogen rates on the green index ratings were very similar to the NDVI of creeping bentgrass. The green index ratings also increased significantly with higher nitrogen rates in both years. The most significant difference among nitrogen treatments occurred from six to eight WAIT in both years. There was no significant difference between the lowest nitrogen rate (3.05 kg ha$^{-1}$) and the no nitrogen treatment in 2015. Nitrogen rates still resulted in a significant increase on the green index of creeping bentgrass from two WAIT to ten WAIT at both the 12.2 kg N ha$^{-1}$ and the 24.4 kg N ha$^{-1}$ treatments and had higher green index ratings than the lower nitrogen rates at ten WAIT.

According to Table 4.7 and Table 4.8, the visual assessment of creeping bentgrass color had similar results to the data taken with the spectrum color meter, only at an even higher significant level. According to the ANOVA results in Table 4.7 and 4.8, the only significant effects on the visual assessment of creeping bentgrass color was from the
nitrogen treatments starting from two WAIT to twelve WAIT in both years with a p-value less than 0.0001. Figure 4.3 shows the visual assessment of creeping bentgrass color every two weeks after the initial treatment under each nitrogen rate in both 2014 and 2015. The visual assessment data seems to reflect a higher level of significance or greater difference between nitrogen treatments than the other color methods. In the last week of the experiment period in 2015 at twelve WAIT, there were already no significant differences among nitrogen rates according to the NDVI data (Figure 4.1), however the visual assessment of color still showed significant increases in color of creeping bentgrass at the higher nitrogen rates.

Table 4.9 shows the digital image analysis ratings for creeping bentgrass color in 2014. This method of color measurement resulted in a significantly lower color rating for the methiozolin treatment compared to the no methiozolin treatment only at eight WAIT (June 15, 2014) which was the same as the NDVI data. There were also significant differences among nitrogen rates from two WAIT to ten WAIT in 2014. According to the DIA color results, there was no significant interactions between the methiozolin treatment and nitrogen rates.

Figure 4.4 (a) shows the effects of nitrogen rates on the DIA of creeping bentgrass color in 2014. Compared with the data taken with the spectrum color meter (NDVI and green index), the DIA measurements were less sensitive to detecting color differences among nitrogen treatments. There were no significant difference between 3.05 kg N ha\(^{-1}\) and the no nitrogen control, and also no significant differences among any of the nitrogen treatments six weeks after the last nitrogen application, namely twelve WAIT.
In conclusion, the methiozolin treatment at the rate of 0.53 kg a.i. ha\textsuperscript{-1} applied four times at two weeks intervals has slightly lower color ratings than the control with no spring application of methiozolin. However, the differences between methiozolin treated and untreated plots was not statistically significant. There were also no significant interactions between methiozolin and nitrogen rates throughout the entire experimental period in each year. The differences in creeping bentgrass color were mainly caused by nitrogen rates. Considering all the color data taken by NDVI, green index, visual assessment and digital image analysis in a normal year like 2014, the color of creeping bentgrass resulted in a significant increase in color with higher nitrogen rates. The greatest difference in color occurred from six WAIT to eight WAIT with each nitrogen rate significantly different than each other. In a warmer year like 2015, there were no significant differences between the 3.05 kg N ha\textsuperscript{-1} and the no nitrogen control. This means that when the weather is conducive to more active creeping bentgrass growth, the 3.05 kg N ha\textsuperscript{-1} applied every other week may be too low to have any significant effect on creeping bentgrass color.

*Creeping Bentgrass Lateral Growth*

Creeping bentgrass lateral growth was measured by monitoring the decrease in size of two 10.79 cm diameter sand holes placed in each treatment with a standard greens cup cutter by creeping bentgrass encroachment. Both grid counting and DIA were conducted to measure the change or decrease in the size of the sand hole. Overall, there were no significant effects from methiozolin treatment on the decrease in the void size. There were no significant interactions between methiozolin and nitrogen rates as well. Like
with the creeping bentgrass color measurements, the only significant effects on the lateral growth and rate of lateral growth of creeping bentgrass into the voids was from the nitrogen rate treatments.

Table 4.10 shows the grid counting results of the change in void size affected by methiozolin rates and nitrogen rates in 2014. The size of the sand hole was not significantly different among treatments at the beginning of the experiment (April 16, 2014). However, after only one nitrogen application, there was already significant effects among the nitrogen rates on the size of the voids (p =0.0010). This significant effect lasted until the last week of the experiment in 2014 (p <.0001, Table 4.10).

In Table 4.11, the sand hole/voids had fewer initial counts before any applications of methiozolin or nitrogen in 2015 than 2014. The ANOVA results of grid counts in 2015 were similar to the grid counts from 2014, showing that nitrogen rate is the only factor with significant effects on the void size (p <.0001).

Figure 4.5 shows the effects of nitrogen rates on the grid counting of the void size in 2014 and 2015. In 2014 [Figure 4.5 (a)], the grid counts of the void size decreased with higher nitrogen rates. There was no significant difference between the 3.05 kg N ha\(^{-1}\) and the 6.1 kg N ha\(^{-1}\) treatments. The latter two lower nitrogen rates started to show significant differences than the no nitrogen treatment only at six WAIT with three applications completed. Both the 12.2 kg N ha\(^{-1}\) and the 24.4 kg N ha\(^{-1}\) had significantly fewer grid counts than the no nitrogen treatment from two WAIT after only one nitrogen application. The highest nitrogen rate, 24.4 kg N ha\(^{-1}\), had significantly fewer grid counts than the 12.2 kg N ha\(^{-1}\) after two applications at four WAIT.
The grid counting results from 2015 were similar to the results from 2014. In Figure 4.5 (b), there was no significant difference between the two lower nitrogen rates and these two lower nitrogen treatments started to show significantly fewer grid counts than the no nitrogen control from six WAIT. The highest nitrogen rate, 24.4 kg N ha\(^{-1}\) had significantly fewer counts or faster creeping bentgrass recovery rate than the 12.2 kg N ha\(^{-1}\) from two WAIT, which was sooner than 2014. However, later in the experiment at ten WAIT, there was no longer any significant differences between the 12.2 kg N ha\(^{-1}\) and the 24.4 kg N ha\(^{-1}\). At the time of twelve WAIT, there was no significant differences between the 6.1 kg N ha\(^{-1}\), the 12.2 kg N ha\(^{-1}\) and the 24.4 kg N ha\(^{-1}\) at twelve WAIT.

According to Table 4.12 and Table 4.13, the ANOVA results of the DIA void size was very similar to the grid counting results. There was no statistically significant difference between methiozolin treated and no methiozolin control, even though methiozolin treatments had a slightly larger void size than no methiozolin control. The DIA results showed that the void size was still mainly affected by nitrogen rates (p <.0001). The significant difference between nitrogen rates started to show after only one application at two WAIT (p = 0.0202, 2014 and p = 0.0001, 2015). No significant interactions found in 2014 but a few interactions occurred from ten WAIT to twelve WAIT in 2015.

Figure 4.6 shows the effects of nitrogen rates on the DIA on the void size in both 2014 and 2015. The DIA results were very similar to the grid counting results. In 2014, the lower nitrogen rates (the 3.05 kg N ha\(^{-1}\) and 6.1 kg N ha\(^{-1}\)) were not significantly different from each other but started to show significantly fewer DIA counts from six
WAIT [Figure 4.6 (a)]. The higher nitrogen rate treatments (the 12.2 kg N ha\(^{-1}\) and 24.4 kg N ha\(^{-1}\)) had significantly fewer DIA counts than the no nitrogen rate treatment as early as two WAIT. The highest nitrogen rate, 24.4 kg ha\(^{-1}\), had significantly fewer void counts or more creeping bentgrass fill-in to voids than the 12.2 kg N ha\(^{-1}\) from four WAIT to ten WAIT. The DIA of the void size in 2015 is also very similar to the grid counting results in Figure 4.5 (b). The only difference in void size was less of a difference among nitrogen treatments during later in the experiment. There were already no statistical significant differences among any of the nitrogen rates on the DIA of the void size at twelve WAIT in 2015. However, the void size of all nitrogen treated plots was much lower than 2014 and close to zero, which means fully creeping bentgrass fill-in/recovery.

Both the grid counting and the DIA methods measured the change in void size to show the lateral growth rate of creeping bentgrass. There was no negative effects or reduction in the lateral growth of creeping bentgrass by methiozolin when applied at the protocol rate of 0.53 kg a.i. ha\(^{-1}\) four times at two-week intervals in the spring.

**Regression of the Effects of Nitrogen Rates**

Regression of the effects of nitrogen rates on creeping bentgrass color was performed to speculate the color of creeping bentgrass under any nitrogen rate between 0 to 24.4 kg N ha\(^{-1}\), and also the color of creeping bentgrass at any time from 0 to 12 WAIT under a certain rate of nitrogen treatments.

Figure 4.7 shows the regression of the NDVI of creeping bentgrass by time under different nitrogen rates in 2014. Because there was a significant interaction between nitrogen rates and year on the NDVI of creeping bentgrass, the NDVI of creeping
bentgrass was not averaged over years. Also, the NDVI data in 2015 were not as representative as 2014 due to the warmer weather conditions in the spring of 2015. As a result, only the NDVI data from 2014 were utilized for the regression. In Figure 4.7, a polynomial regression fits the NDVI of creeping bentgrass under each nitrogen rate from 0 WAIT to 12 WAIT with all the R-squared values above 0.98. A model was developed according to this regression result.

\[ y = At^2 + Bt + C \]

\( y = \) the NDVI of creeping bentgrass  
\( t = \) weeks after the initial treatment  
\( A = \) binomial coefficient determined by the nitrogen rate  
\( B = \) monomial coefficient determined by the nitrogen rate  
\( C = 0.4868 \)

The constant \( C \) was averaged from the five regression formulas under each nitrogen rate, because \( C \) stands for the NDVI of creeping bentgrass when \( t \) equals zero. This means \( C \) is the NDVI of creeping bentgrass before the first nitrogen application, which should not be influenced by the nitrogen rate and should be a constant.

To determine the parametric equation of coefficient-\( A \) and coefficient-\( B \), another two regressions were developed for coefficient-\( A \) and coefficient-\( B \) separately by nitrogen rates. Since the nitrogen rates in the experiment were designed to be an exponential function of 1.525, so the logarithm of the actual nitrogen rate was used in the regression of coefficient-\( A \) and coefficient-\( B \). The actual nitrogen rated applied in the experiment has a relationship with \( x \):
\[ N = 1.525 \times 2^x \]

\( N \) = actual nitrogen rate applied
\( x \) = logarithmic nitrogen rate

Figure 4.8 and Figure 4.9 are regression of coefficient-A and coefficient-B, respectively. According to the result of curve fitting, a linear model was used for both coefficients.

\[
A = -0.0008x - 0.0006 \\
B = 0.0095x + 0.0255
\]

\( A \) = coefficient-A
\( B \) = coefficient-B
\( x \) = logarithmic nitrogen rate = \( \log_2 \left( \frac{N}{1.525} \right) \)

After adding the parametric equation of coefficient-A and coefficient-B, the original regression function of the NDVI of creeping bentgrass was transformed to a function of NDVI of creeping bentgrass determined by time and nitrogen rate.

\[
y = \left[ (-0.0008) \times \log_2 N - 0.000113 \right] t^2 + \left[ (0.0095) \times \log_2 N + 0.019716 \right] t + 0.4868
\]

\( y \) = the NDVI of creeping bentgrass
\( N \) = actual nitrogen rate applied
\( t \) = weeks after the initial treatment

Regression of the effects of nitrogen rates on the lateral growth of creeping bentgrass was also performed. Since the interaction of nitrogen rates and year on the grid counts of the void size was not significant, the data of the grid counts of void size was
averaged over two years for the regression. Figure 4.10 shows the regression of the grid counting of the void size by time under different nitrogen rates. For the highest nitrogen rate, 24.4 kg N ha\(^{-1}\), only the data before the grid counts reached zero was included for regression. The model of the grid counting of the void size time is:

\[ y = Kt + b \]

- \( y \) = the grid counting of the void size
- \( t \) = weeks after initial treatment
- \( K \) = slope determined by nitrogen rate
- \( b = 99.4762 \)

The interception of all regression lines under each nitrogen rate treatment should be the same, because it stands for the initial size of the voids at when \( t \) equals zero, which also means before any treatments. So \( b \) is the average of all the intercepts. According to the regression results, there was an inversely-proportional relationship between the size of the voids and the time and the slope of the regression line was influenced by the nitrogen rate. A regression of \( K \) by nitrogen rates was also performed (Figure 4.11), but unlike the regression for coefficient-A and coefficient-B for creeping bentgrass color, the regression of \( K \) is more linear to the actual nitrogen rate applied.

\[ K = -0.1886N - 5.6229 \]

- \( K \) = slope
- \( N \) = actual nitrogen rate applied

The regression function of grid counts of the void size over time under different nitrogen rates is as follows:
\[ y = -0.1886N \cdot t - 5.6229t + 99.4762 \]

y = the grid counting of the void size  
t = weeks after initial treatment  
N = actual nitrogen rate applied

In the regression, the color of creeping bentgrass was represented by a polynomial relation with time and the curvature of the polynomial function was affected by the nitrogen rate. The higher rate of nitrogen applied, the larger was the curvature. This indicates that at higher nitrogen rates, creeping bentgrass color increases more quickly and reaches higher maximum reading. The model developed for the NDVI of creeping bentgrass affected by nitrogen rates at each time is helpful for the estimation of creeping bentgrass color under any nitrogen rate treatment at any time between 0 WAIT to 12 WAIT. The regression of the grid counts of the void size shows the lateral growth/growth rate of creeping bentgrass is constant through time and is only influenced by the nitrogen rate applied. The slope of the linear regression function stands for the lateral growth rate of creeping bentgrass under specific nitrogen rates. The higher the nitrogen rate applied, the steeper is the slope, which means higher nitrogen rates will promote the lateral growth rate of creeping bentgrass. There is also a linear relation between the creeping bentgrass linear growth and the nitrogen rate applied.

Conclusions

In conclusion, even though the methiozolin treatment at the rate of 0.53 kg ha\(^{-1}\) applied treatment in the spring, the difference between the methiozolin and no methiozolin treatment was not significant. There was also no significant interactions between
methiozolin and nitrogen rates throughout the entire experimental period in each year. The difference in creeping bentgrass color was mainly caused by the nitrogen rates. In a normal year like 2014, the color of creeping bentgrass increased significantly with higher nitrogen rates based on the NDVI, green index, DIA and visual assessment methods. The greatest difference in creeping bentgrass color occurred from six WAIT to eight WAIT when the color significantly increased with each incremental nitrogen rate. In a warmer year like 2015, there were no significant differences between the lowest nitrogen rate, 3.05 kg ha$^{-1}$, and no nitrogen control. This implies that when creeping bentgrass is actively growing, a 3.05 kg N ha$^{-1}$ applied every other week is too low to have any significant effects on the color of creeping bentgrass.

Grid counting and digital image analysis showed that the lateral growth rate of creeping bentgrass was mainly affected by the nitrogen rates. There were no significantly negative effects or decreases in the lateral growth/growth rate of creeping bentgrass by methiozolin when applied at the protocol rate of 0.53 kg ha at four times at two-week intervals in the spring.

According to the regression results, there was a quadratic relation between the color of creeping bentgrass and time. The curvature and the peak of the function was only affected by the nitrogen rates. The higher rate of nitrogen applied, the larger was the curvature and the higher was the peak. This indicated that at higher nitrogen rates, creeping bentgrass color increased more quickly and achieved darker green. The model developed for the NDVI of creeping bentgrass affected by nitrogen rates at each time is helpful for the estimation of creeping bentgrass color under any nitrogen rate treatment at
any time from 0 WAIT to 12 WAIT. The regression of the grid counts of the void size showed there was linear relationship between void size and time, and the slope of the model was the lateral growth rate of creeping bentgrass under each nitrogen rate. This means the lateral growth rate of creeping bentgrass was constant through time and was only influenced by the nitrogen rate applied. Also, the higher the nitrogen rate applied, the steeper was the slope, which means higher nitrogen rates will promote the lateral growth rate of creeping bentgrass.
Table 4.1. All treatments of nitrogen and methiozolin on creeping bentgrass lateral growth.

<table>
<thead>
<tr>
<th>Nitrogen rate (kg N ha(^{-1}))^†</th>
<th>Methiozolin rate (kg a.i. ha(^{-1}))</th>
<th>M0N0</th>
<th>M0N1</th>
<th>M1N0</th>
<th>M1N1</th>
<th>M0N2</th>
<th>M1N2</th>
<th>M0N3</th>
<th>M1N3</th>
<th>M0N4</th>
<th>M1N4</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (N0)</td>
<td>0 (M0)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3.05 (N1)</td>
<td>M0N1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.1 (N2)</td>
<td>M0N2</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>12.2 (N4)</td>
<td>M0N3</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>24.4 (N8)</td>
<td>M0N4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

† All treatments was applied at two weeks interval (twice per month) and totally four applications were made in each year.
Table 4.2. Application dates and rates of methiozolin and nitrogen on creeping bentgrass lateral growth, 2014 and 2015.

<table>
<thead>
<tr>
<th>Air temp. (high/low, C)</th>
<th>M1 (kg a.i. ha(^{-1}))</th>
<th>N1 (kg N ha(^{-1}))</th>
<th>N2 (kg N ha(^{-1}))</th>
<th>N3 (kg N ha(^{-1}))</th>
<th>N4 (kg N ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23 Apr</td>
<td>14.3/2.8</td>
<td>0.53</td>
<td>3.05</td>
<td>6.1</td>
<td>12.2</td>
</tr>
<tr>
<td>7 May</td>
<td>29.1/13.3</td>
<td>0.53</td>
<td>3.05</td>
<td>6.1</td>
<td>12.2</td>
</tr>
<tr>
<td>21 May</td>
<td>26.5/17.3</td>
<td>0.53</td>
<td>3.05</td>
<td>6.1</td>
<td>12.2</td>
</tr>
<tr>
<td>4 Jun</td>
<td>22.7/15.2</td>
<td>0.53</td>
<td>3.05</td>
<td>6.1</td>
<td>12.2</td>
</tr>
<tr>
<td>Yearly total</td>
<td>7.32</td>
<td>12.2</td>
<td>24.4</td>
<td>48.8</td>
<td>97.6</td>
</tr>
<tr>
<td>2015</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 May</td>
<td>28.8/12.2</td>
<td>0.53</td>
<td>3.05</td>
<td>6.1</td>
<td>12.2</td>
</tr>
<tr>
<td>18 May</td>
<td>26.7/20.3</td>
<td>0.53</td>
<td>3.05</td>
<td>6.1</td>
<td>12.2</td>
</tr>
<tr>
<td>1 Jun</td>
<td>13.0/9.5</td>
<td>0.53</td>
<td>3.05</td>
<td>6.1</td>
<td>12.2</td>
</tr>
<tr>
<td>15 Jun</td>
<td>30.4/21.1</td>
<td>0.53</td>
<td>3.05</td>
<td>6.1</td>
<td>12.2</td>
</tr>
<tr>
<td>Yearly total</td>
<td>7.32</td>
<td>12.2</td>
<td>24.4</td>
<td>48.8</td>
<td>97.6</td>
</tr>
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</table>
Table 4.3. NDVI of creeping bentgrass influenced by methiozolin rates and nitrogen rates on creeping bentgrass lateral growth on golf greens, 2014.

<table>
<thead>
<tr>
<th>Methiozolin</th>
<th>Dates</th>
<th>Dates</th>
<th>Dates</th>
<th>Dates</th>
<th>Dates</th>
<th>Dates</th>
<th>Dates</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 WAIT</td>
<td>2 WAIT</td>
<td>4 WAIT</td>
<td>6 WAIT</td>
<td>8 WAIT</td>
<td>10 WAIT</td>
<td>12 WAIT</td>
<td></td>
</tr>
<tr>
<td>0 kg a.i. ha⁻¹</td>
<td>0.488a†</td>
<td>0.567a</td>
<td>0.638a</td>
<td>0.674a</td>
<td>0.712a</td>
<td>0.724a</td>
<td>0.711a</td>
<td></td>
</tr>
<tr>
<td>0.53 kg a.i. ha⁻¹</td>
<td>0.487a</td>
<td>0.564a</td>
<td>0.633a</td>
<td>0.668a</td>
<td>0.703b</td>
<td>0.719a</td>
<td>0.713a</td>
<td></td>
</tr>
<tr>
<td>Nitrogen rates</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>0 kg N ha⁻¹</td>
<td>0.489a</td>
<td>0.520a</td>
<td>0.575a</td>
<td>0.621a</td>
<td>0.651a</td>
<td>0.691a</td>
<td>0.693a</td>
<td></td>
</tr>
<tr>
<td>3.05 kg N ha⁻¹</td>
<td>0.492a</td>
<td>0.543ab</td>
<td>0.606b</td>
<td>0.642b</td>
<td>0.686b</td>
<td>0.703ab</td>
<td>0.701b</td>
<td></td>
</tr>
<tr>
<td>6.1 kg N ha⁻¹</td>
<td>0.481a</td>
<td>0.558b</td>
<td>0.619b</td>
<td>0.663c</td>
<td>0.587c</td>
<td>0.714b</td>
<td>0.701b</td>
<td></td>
</tr>
<tr>
<td>12.2 kg N ha⁻¹</td>
<td>0.496a</td>
<td>0.593c</td>
<td>0.672c</td>
<td>0.701d</td>
<td>0.745d</td>
<td>0.743c</td>
<td>0.728c</td>
<td></td>
</tr>
<tr>
<td>24.4 kg N ha⁻¹</td>
<td>0.477a</td>
<td>0.615c</td>
<td>0.707d</td>
<td>0.730e</td>
<td>0.769e</td>
<td>0.757c</td>
<td>0.737d</td>
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ANOVA results

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<th>M*N</th>
</tr>
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<td>0.5782</td>
<td>&lt;.0001</td>
<td>0.2067</td>
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†Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 4.4. NDVI of creeping bentgrass influenced by methiozolin rates and nitrogen rates on creeping bentgrass lateral growth on golf greens, 2015.

<table>
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<td>2 WAIT</td>
<td>4 WAIT</td>
<td>6 WAIT</td>
<td>8 WAIT</td>
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<td>Methiozolin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 kg a.i. ha⁻¹</td>
<td>0.683a†</td>
<td>0.653a</td>
<td>0.708a</td>
<td>0.746a</td>
<td>0.712a</td>
<td>0.725a</td>
<td>0.715a</td>
</tr>
<tr>
<td>0.53 kg a.i. ha⁻¹</td>
<td>0.668b</td>
<td>0.641a</td>
<td>0.705a</td>
<td>0.745a</td>
<td>0.710a</td>
<td>0.718a</td>
<td>0.709a</td>
</tr>
<tr>
<td>Nitrogen rates</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 kg N ha⁻¹</td>
<td>0.671a</td>
<td>0.630a</td>
<td>0.683a</td>
<td>0.729a</td>
<td>0.689a</td>
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<td>0.706a</td>
</tr>
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<td>0.682a</td>
<td>0.645ab</td>
<td>0.682ab</td>
<td>0.736ab</td>
<td>0.698ab</td>
<td>0.709a</td>
<td>0.716a</td>
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<td>0.656ab</td>
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<td>0.741b</td>
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<td>0.642ab</td>
<td>0.720c</td>
<td>0.754c</td>
<td>0.724cd</td>
<td>0.734b</td>
<td>0.716a</td>
</tr>
<tr>
<td>24.4 kg N ha⁻¹</td>
<td>0.678a</td>
<td>0.660b</td>
<td>0.734c</td>
<td>0.768d</td>
<td>0.733d</td>
<td>0.737b</td>
<td>0.712a</td>
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ANOVA results

<p>| | | | | | | | |</p>
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<tbody>
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<td>Methiozolin</td>
<td>0.0402</td>
<td>0.1431</td>
<td>0.5084</td>
<td>0.7491</td>
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<td>0.2653</td>
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<tr>
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<td>0.7778</td>
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<td>0.3763</td>
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†Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 4.5. Green Index of creeping bentgrass influenced by methiozolin rates and nitrogen rates on creeping bentgrass lateral growth on golf greens, 2014.

<table>
<thead>
<tr>
<th>Methiozolin</th>
<th>2 WAIT</th>
<th>4 WAIT</th>
<th>6 WAIT</th>
<th>8 WAIT</th>
<th>10 WAIT</th>
<th>12 WAIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 kg a.i. ha⁻¹</td>
<td>6.06a†</td>
<td>6.56a</td>
<td>6.84a</td>
<td>6.97a</td>
<td>7.17a</td>
<td>7.05a</td>
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<tr>
<td>0.53 kg a.i. ha⁻¹</td>
<td>6.04a</td>
<td>6.51a</td>
<td>6.81a</td>
<td>6.98a</td>
<td>7.14a</td>
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</table>

<table>
<thead>
<tr>
<th>Nitrogen rates</th>
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<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0 kg N ha⁻¹</td>
<td>5.75a</td>
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<td>6.59a</td>
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<td>6.88a</td>
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<tr>
<td>3.05 kg N ha⁻¹</td>
<td>5.86ab</td>
<td>6.28a</td>
<td>6.62b</td>
<td>6.80b</td>
<td>7.03a</td>
<td>6.97b</td>
</tr>
<tr>
<td>6.1 kg N ha⁻¹</td>
<td>6.00b</td>
<td>6.46b</td>
<td>6.77c</td>
<td>6.91c</td>
<td>7.08a</td>
<td>7.01b</td>
</tr>
<tr>
<td>12.2 kg N ha⁻¹</td>
<td>6.25c</td>
<td>6.78c</td>
<td>7.03d</td>
<td>7.19d</td>
<td>7.19b</td>
<td>7.15c</td>
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<td>24.4 kg N ha⁻¹</td>
<td>6.39c</td>
<td>6.98d</td>
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ANOVA results

<p>| | | | | | | |</p>
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<td>&lt;.0001</td>
<td>&lt;.0001</td>
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<td>0.8614</td>
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</tbody>
</table>

†Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 4.6. Green Index of creeping bentgrass influenced by methiozolin rates and nitrogen rates on creeping bentgrass lateral growth on golf greens, 2015.

<table>
<thead>
<tr>
<th>Methiozolin</th>
<th>0 WAIT</th>
<th>2 WAIT</th>
<th>4 WAIT</th>
<th>6 WAIT</th>
<th>8 WAIT</th>
<th>10 WAIT</th>
<th>12 WAIT</th>
</tr>
</thead>
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<tr>
<td>0 kg a.i. ha⁻¹</td>
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<td>6.98a</td>
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<tr>
<td>0.53 kg a.i. ha⁻¹</td>
<td>6.78a</td>
<td>6.72a</td>
<td>6.93a</td>
<td>7.26a</td>
<td>7.05a</td>
<td>7.16a</td>
<td>7.01a</td>
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<tr>
<td>Nitrogen rates</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 kg N ha⁻¹</td>
<td>6.77a</td>
<td>6.70a</td>
<td>6.81a</td>
<td>7.14a</td>
<td>6.91a</td>
<td>7.09ab</td>
<td>6.97ab</td>
</tr>
<tr>
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<td>6.87a</td>
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<td>6.85a</td>
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<td>7.06a</td>
<td>6.95a</td>
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<td>6.82a</td>
<td>6.76a</td>
<td>6.91a</td>
<td>7.22b</td>
<td>7.04b</td>
<td>7.16bc</td>
<td>6.99abc</td>
</tr>
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<td>12.2 kg N ha⁻¹</td>
<td>6.79a</td>
<td>6.81a</td>
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<td>7.16c</td>
<td>7.26cd</td>
<td>7.04bc</td>
</tr>
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<td>24.4 kg N ha⁻¹</td>
<td>6.83a</td>
<td>6.79a</td>
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ANOVA results

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<th>M*N</th>
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<td>0.7128</td>
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<tr>
<td></td>
<td>0.2718</td>
<td>&lt;.0001</td>
<td>0.3889</td>
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</table>

†Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 4.7. Visual assessment of creeping bentgrass color influenced by methiozolin rates and nitrogen rates on creeping bentgrass lateral growth on golf greens, 2014.

<table>
<thead>
<tr>
<th>Methiozolin</th>
<th>0 WAIT</th>
<th>2 WAIT</th>
<th>4 WAIT</th>
<th>6 WAIT</th>
<th>8 WAIT</th>
<th>10 WAIT</th>
<th>12 WAIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methiozolin 0 kg a.i. ha⁻¹</td>
<td>5.5a†</td>
<td>6.0a</td>
<td>6.2a</td>
<td>6.5a</td>
<td>7.1a</td>
<td>7.0a</td>
<td>6.9a</td>
</tr>
<tr>
<td>Methiozolin 0.53 kg a.i. ha⁻¹</td>
<td>5.5a</td>
<td>6.2a</td>
<td>6.3a</td>
<td>6.5a</td>
<td>7.0a</td>
<td>6.9a</td>
<td>6.9a</td>
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<tr>
<td>Nitrogen rates</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen rates 0 kg N ha⁻¹</td>
<td>5.5a</td>
<td>5.3a</td>
<td>5.1a</td>
<td>5.5a</td>
<td>5.9a</td>
<td>6.3a</td>
<td>6.2a</td>
</tr>
<tr>
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<td>5.8b</td>
<td>5.5b</td>
<td>5.6a</td>
<td>6.4b</td>
<td>6.6ab</td>
<td>6.4ab</td>
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<tr>
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<td>5.5a</td>
<td>5.9b</td>
<td>6.0c</td>
<td>6.3b</td>
<td>6.8c</td>
<td>6.8b</td>
<td>6.8b</td>
</tr>
<tr>
<td>Nitrogen rates 12.2 kg N ha⁻¹</td>
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<td>6.5c</td>
<td>6.9d</td>
<td>7.1c</td>
<td>7.7d</td>
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<td>8.4e</td>
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<td>7.8d</td>
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ANOVA results

<table>
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<th>Methiozolin</th>
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<th>M*N</th>
</tr>
</thead>
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<td>&lt;.0001</td>
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<tr>
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<td>-</td>
<td>0.1363</td>
<td>0.6294</td>
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</tbody>
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†Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 4.8. Visual assessment of creeping bentgrass color influenced by methiozolin rates and nitrogen rates on creeping bentgrass lateral growth on golf greens, 2015.

<table>
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<th>Methiozolin</th>
<th>Dates</th>
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<th>2 WAIT</th>
<th>4 WAIT</th>
<th>6 WAIT</th>
<th>8 WAIT</th>
<th>10 WAIT</th>
<th>12 WAIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 kg a.i. ha(^{-1})</td>
<td>5.5a†</td>
<td>6.1a</td>
<td>6.7a</td>
<td>7.2a</td>
<td>7.2a</td>
<td>6.6a</td>
<td>6.4a</td>
<td></td>
</tr>
<tr>
<td>0.53 kg a.i. ha(^{-1})</td>
<td>5.3a</td>
<td>6.2a</td>
<td>6.6a</td>
<td>7.1a</td>
<td>7.2a</td>
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<tr>
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<td>4 WAIT</td>
<td>6 WAIT</td>
<td>8 WAIT</td>
<td>10 WAIT</td>
<td>12 WAIT</td>
</tr>
<tr>
<td>0 kg N ha(^{-1})</td>
<td>5.4a</td>
<td>5.1a</td>
<td>5.0a</td>
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<td>4.9a</td>
<td>4.7a</td>
<td>5.1a</td>
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</tr>
<tr>
<td>3.05 kg N ha(^{-1})</td>
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<td>5.3a</td>
<td>5.7b</td>
<td>6.0b</td>
<td>6.0b</td>
<td>5.7b</td>
<td>5.8b</td>
<td></td>
</tr>
<tr>
<td>6.1 kg N ha(^{-1})</td>
<td>5.5a</td>
<td>5.3b</td>
<td>6.6c</td>
<td>7.6c</td>
<td>7.7c</td>
<td>6.8c</td>
<td>6.6c</td>
<td></td>
</tr>
<tr>
<td>12.2 kg N ha(^{-1})</td>
<td>5.3a</td>
<td>6.7c</td>
<td>7.5d</td>
<td>8.3d</td>
<td>8.6d</td>
<td>8.0d</td>
<td>7.4d</td>
<td></td>
</tr>
<tr>
<td>24.4 kg N ha(^{-1})</td>
<td>5.3a</td>
<td>7.3d</td>
<td>8.5e</td>
<td>8.9e</td>
<td>8.9d</td>
<td>8.3d</td>
<td>7.6d</td>
<td></td>
</tr>
</tbody>
</table>

ANOVA results

| Methiozolin | 0.2770 | 0.5617 | 0.6450 | 0.0708 | 0.7970 | 0.5921 | 0.3605 |
| Nitrogen rates | 0.6822 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 |
| M*N        | 0.3731 | 0.6891 | 0.3014 | 0.8277 | 0.2169 | 0.0290 | 0.8121 |

†Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 4.9. Digital image analysis of creeping bentgrass color influenced by methiozolin rates and nitrogen rates on creeping bentgrass lateral growth on golf greens, 2014.

<table>
<thead>
<tr>
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<th>Dates</th>
<th>0 WAIT</th>
<th>2 WAIT</th>
<th>4 WAIT</th>
<th>6 WAIT</th>
<th>8 WAIT</th>
<th>10 WAIT</th>
<th>12 WAIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methiozolin</td>
<td>0 kg a.i. ha(^{-1})</td>
<td>0.294a</td>
<td>0.327a</td>
<td>0.368a</td>
<td>0.393a</td>
<td>0.398a</td>
<td>0.396a</td>
<td>0.377a</td>
</tr>
<tr>
<td></td>
<td>0.53 kg a.i. ha(^{-1})</td>
<td>0.274a</td>
<td>0.325a</td>
<td>0.363a</td>
<td>0.391a</td>
<td>0.393b</td>
<td>0.396a</td>
<td>0.379a</td>
</tr>
<tr>
<td>Nitrogen rates</td>
<td>0 kg N ha(^{-1})</td>
<td>0.294a</td>
<td>0.311a</td>
<td>0.342a</td>
<td>0.370a</td>
<td>0.371a</td>
<td>0.394ab</td>
<td>0.377a</td>
</tr>
<tr>
<td></td>
<td>3.05 kg N ha(^{-1})</td>
<td>0.295a</td>
<td>0.316a</td>
<td>0.349a</td>
<td>0.374a</td>
<td>0.375a</td>
<td>0.392a</td>
<td>0.379a</td>
</tr>
<tr>
<td></td>
<td>6.1 kg N ha(^{-1})</td>
<td>0.295a</td>
<td>0.323b</td>
<td>0.358b</td>
<td>0.385b</td>
<td>0.386b</td>
<td>0.391a</td>
<td>0.375a</td>
</tr>
<tr>
<td></td>
<td>12.2 kg N ha(^{-1})</td>
<td>0.292a</td>
<td>0.333c</td>
<td>0.377c</td>
<td>0.401c</td>
<td>0.409c</td>
<td>0.397b</td>
<td>0.378a</td>
</tr>
<tr>
<td></td>
<td>24.4 kg N ha(^{-1})</td>
<td>0.293a</td>
<td>0.348d</td>
<td>0.402d</td>
<td>0.430d</td>
<td>0.436d</td>
<td>0.406c</td>
<td>0.381a</td>
</tr>
</tbody>
</table>

ANOVA results

|                     | Methiozolin | 0.8451 | 0.2676 | 0.0613 | 0.1345 | 0.0140 | 0.9085 | 0.5812 |
|                     | Nitrogen rates | 0.5574 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.4383 |
|                     | M*N          | 0.0242 | 0.2005 | 0.8895 | 0.8710 | 0.2487 | 0.0411 | 0.8402 |

\(†\)Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 4.10. Grid counting of the void size influenced by methiozolin rates and nitrogen rates on creeping bentgrass lateral growth on golf greens, 2014.

<table>
<thead>
<tr>
<th></th>
<th>Methiozolin</th>
<th>Nitrogen rates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 kg a.i. ha(^{-1})</td>
<td>0 kg N ha(^{-1})</td>
</tr>
<tr>
<td>0 kg a.i. ha(^{-1})</td>
<td>105.1a&lt;sup&gt;†&lt;/sup&gt;</td>
<td>105.8</td>
</tr>
<tr>
<td>0.53 kg a.i. ha(^{-1})</td>
<td>103.1</td>
<td>89.7</td>
</tr>
<tr>
<td>Dates</td>
<td>0 WAIT</td>
<td>2 WAIT</td>
</tr>
<tr>
<td></td>
<td>105.1a†</td>
<td>89.7a</td>
</tr>
<tr>
<td></td>
<td>103.1a</td>
<td>89.0a</td>
</tr>
<tr>
<td></td>
<td>105.8a</td>
<td>94.0a</td>
</tr>
<tr>
<td></td>
<td>101.8a</td>
<td>89.7ab</td>
</tr>
<tr>
<td></td>
<td>103.4a</td>
<td>92.8a</td>
</tr>
<tr>
<td></td>
<td>106.0a</td>
<td>85.5bc</td>
</tr>
<tr>
<td></td>
<td>103.3a</td>
<td>84.8c</td>
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ANOVA results

<table>
<thead>
<tr>
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<th>Methiozolin</th>
<th>Nitrogen rates</th>
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<tbody>
<tr>
<td>Methiozolin</td>
<td>0.1648</td>
<td>0.2776</td>
</tr>
<tr>
<td>Nitrogen rates</td>
<td>0.5970</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>M*N</td>
<td>0.7348</td>
<td>&lt;.001</td>
</tr>
<tr>
<td></td>
<td>0.2724</td>
<td>&lt;.001</td>
</tr>
<tr>
<td></td>
<td>0.1588</td>
<td>&lt;.001</td>
</tr>
<tr>
<td></td>
<td>0.0720</td>
<td>&lt;.001</td>
</tr>
<tr>
<td></td>
<td>0.6012</td>
<td>&lt;.001</td>
</tr>
<tr>
<td></td>
<td>0.0249</td>
<td>0.0010</td>
</tr>
<tr>
<td></td>
<td>0.1350</td>
<td>&lt;.001</td>
</tr>
<tr>
<td></td>
<td>0.0604</td>
<td>&lt;.001</td>
</tr>
<tr>
<td></td>
<td>0.3403</td>
<td>&lt;.001</td>
</tr>
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<td></td>
<td>0.4558</td>
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<td>0.5269</td>
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</tr>
<tr>
<td></td>
<td>0.3037</td>
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</tbody>
</table>

†Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 4.11. Grid counting of the void size influenced by methiozolin rates and nitrogen rates on creeping bentgrass lateral growth on golf greens, 2015.

<table>
<thead>
<tr>
<th>Methiozolin</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 WAIT</td>
</tr>
<tr>
<td>0 kg a.i. ha(^{-1})</td>
<td>96.7a†</td>
</tr>
<tr>
<td>0.53 kg a.i. ha(^{-1})</td>
<td>96.4a</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nitrogen rates</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 WAIT</td>
</tr>
<tr>
<td>0 kg N ha(^{-1})</td>
<td>97.9a</td>
</tr>
<tr>
<td>3.05 kg N ha(^{-1})</td>
<td>96.4a</td>
</tr>
<tr>
<td>6.1 kg N ha(^{-1})</td>
<td>96.3a</td>
</tr>
<tr>
<td>12.2 kg N ha(^{-1})</td>
<td>95.3a</td>
</tr>
<tr>
<td>24.4 kg N ha(^{-1})</td>
<td>96.8a</td>
</tr>
</tbody>
</table>

ANOVA results

<table>
<thead>
<tr>
<th></th>
<th>Methiozolin</th>
<th>Nitrogen rates</th>
<th>M*N</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8461</td>
<td>0.7177</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>0.7337</td>
<td>0.0004</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>0.1279</td>
<td>0.2386</td>
<td>0.5520</td>
<td>0.3809</td>
</tr>
<tr>
<td>0.1960</td>
<td>0.4820</td>
<td>0.0438</td>
<td>0.0438</td>
</tr>
<tr>
<td>0.5478</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 4.12. Digital image analysis of the void size influenced by methiozolin rates and nitrogen rates on creeping bentgrass lateral growth on golf greens, 2014.

<table>
<thead>
<tr>
<th>Methiozolin</th>
<th>Dates</th>
<th>0 WAIT</th>
<th>2 WAIT</th>
<th>4 WAIT</th>
<th>6 WAIT</th>
<th>8 WAIT</th>
<th>10 WAIT</th>
<th>12 WAIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 kg a.i. ha⁻¹</td>
<td>15419.4a†</td>
<td>10752.8a</td>
<td>8867.0a</td>
<td>7713.7a</td>
<td>5206.1a</td>
<td>3543.1a</td>
<td>2610.1a</td>
<td></td>
</tr>
<tr>
<td>0.53 kg a.i. ha⁻¹</td>
<td>15161.4a</td>
<td>10729.5a</td>
<td>8819.7a</td>
<td>7326.8a</td>
<td>5546.0a</td>
<td>3968.3a</td>
<td>2591.4a</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Nitrogen rates</th>
<th>Dates</th>
<th>0 WAIT</th>
<th>2 WAIT</th>
<th>4 WAIT</th>
<th>6 WAIT</th>
<th>8 WAIT</th>
<th>10 WAIT</th>
<th>12 WAIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 kg N ha⁻¹</td>
<td>16209.1a</td>
<td>11509.3a</td>
<td>10603.7a</td>
<td>9558.0a</td>
<td>8236.7a</td>
<td>6257.8a</td>
<td>5892.8a</td>
<td></td>
</tr>
<tr>
<td>3.05 kg N ha⁻¹</td>
<td>14701.3a</td>
<td>10819.8ab</td>
<td>10010.6ab</td>
<td>8716.1b</td>
<td>7064.5b</td>
<td>5180.9b</td>
<td>3253.3b</td>
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</tr>
<tr>
<td>6.1 kg N ha⁻¹</td>
<td>15069.5a</td>
<td>10830.2ab</td>
<td>9428.5b</td>
<td>7990.8b</td>
<td>6542.3b</td>
<td>4851.6b</td>
<td>3188.0b</td>
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</tr>
<tr>
<td>12.2 kg N ha⁻¹</td>
<td>15418.0a</td>
<td>10487.8b</td>
<td>7914.8c</td>
<td>6506.3c</td>
<td>3994.3c</td>
<td>2315.0c</td>
<td>868.7c</td>
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</tr>
<tr>
<td>24.4 kg N ha⁻¹</td>
<td>15054.0a</td>
<td>10058.8b</td>
<td>6259.1d</td>
<td>4080.1d</td>
<td>1042.4d</td>
<td>4851.6d</td>
<td>3188.0b</td>
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</tbody>
</table>

ANOVA results

<table>
<thead>
<tr>
<th></th>
<th>Methiozolin</th>
<th>Nitrogen rates</th>
<th>M*N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5935</td>
<td>0.3596</td>
<td>0.2914</td>
</tr>
<tr>
<td>0.9247</td>
<td>0.0202</td>
<td>0.2488</td>
<td>0.6247</td>
</tr>
<tr>
<td>0.8178</td>
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<td>0.5182</td>
<td>0.4394</td>
</tr>
<tr>
<td>0.7213</td>
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<td>0.3274</td>
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<tr>
<td>0.1952</td>
<td>&lt;.0001</td>
<td>0.6620</td>
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</tr>
<tr>
<td>0.0738</td>
<td>&lt;.0001</td>
<td>0.4394</td>
<td></td>
</tr>
<tr>
<td>0.9622</td>
<td>&lt;.0001</td>
<td>0.3520</td>
<td></td>
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</tbody>
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† Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Table 4.13. Digital image analysis of the void size influenced by methiozolin rates and nitrogen rates on creeping bentgrass lateral growth on golf greens, 2015.

<table>
<thead>
<tr>
<th></th>
<th>Dates</th>
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<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 WAIT</td>
<td>2 WAIT</td>
<td>4 WAIT</td>
<td>6 WAIT</td>
<td>8 WAIT</td>
<td>10 WAIT</td>
<td>12 WAIT</td>
</tr>
<tr>
<td>Methiozolin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 kg a.i. ha⁻¹</td>
<td>11361.4a†</td>
<td>8664.7a</td>
<td>6645.9a</td>
<td>4319.5a</td>
<td>2280.9a</td>
<td>1303.7a</td>
<td>415.9a</td>
</tr>
<tr>
<td>0.53 kg a.i. ha⁻¹</td>
<td>11286.5a</td>
<td>8787.8a</td>
<td>6916.2a</td>
<td>4835.7a</td>
<td>2793.1a</td>
<td>1463.0a</td>
<td>698.7a</td>
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<tr>
<td>Nitrogen rates</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 kg N ha⁻¹</td>
<td>11238.7a</td>
<td>9634.3a</td>
<td>8106.3a</td>
<td>6921.8a</td>
<td>4625.5a</td>
<td>3806.6a</td>
<td>1979.9a</td>
</tr>
<tr>
<td>3.05 kg N ha⁻¹</td>
<td>11453.1a</td>
<td>8961.8ab</td>
<td>7172.1ab</td>
<td>5559.4b</td>
<td>3611.3ab</td>
<td>1491.3b</td>
<td>370.7b</td>
</tr>
<tr>
<td>6.1 kg N ha⁻¹</td>
<td>11332.7a</td>
<td>9094.2a</td>
<td>7182.8ab</td>
<td>5279.3b</td>
<td>3042.1b</td>
<td>1217.0b</td>
<td>268.4b</td>
</tr>
<tr>
<td>12.2 kg N ha⁻¹</td>
<td>11298.8a</td>
<td>8350.4b</td>
<td>6466.8b</td>
<td>3774.8c</td>
<td>1350.7c</td>
<td>394.8bc</td>
<td>142.8b</td>
</tr>
<tr>
<td>24.4 kg N ha⁻¹</td>
<td>11296.6a</td>
<td>7590.5c</td>
<td>4977.1c</td>
<td>1352.7d</td>
<td>55.4d</td>
<td>7.0c</td>
<td>24.8b</td>
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</table>

ANOVA results

<table>
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<tr>
<th></th>
<th>Methiozolin</th>
<th>Nitrogen rates</th>
<th>M*N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.7405</td>
<td>0.5644</td>
<td>0.3570</td>
</tr>
<tr>
<td></td>
<td>0.9802</td>
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<td>&lt;.0001</td>
</tr>
<tr>
<td>M*N</td>
<td>0.0811</td>
<td>0.2355</td>
<td>0.2380</td>
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†Means followed by the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
Figure 4.1. The effect of nitrogen rates on the NDVI of creeping bentgrass 2, 4, 6, 8, 10, and 12 weeks after initial treatment in a) 2014 and b) 2015.

1 Means with the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
2 Nitrogen treatments: N0 = 0 kg N ha\(^{-1}\), N1 = 3.05 kg N ha\(^{-1}\), N2 = 6.1 kg N ha\(^{-1}\), N3 = 12.2 kg N ha\(^{-1}\), N4 = 24.4 kg N ha\(^{-1}\).
Figure 4.2. The effect of nitrogen rates on the green index of creeping bentgrass 2, 4, 6, 8, 10, and 12 weeks after initial treatment in a) 2014 and b) 2015.

1 Means with the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.

2 Nitrogen treatments: N0 = 0 kg N ha⁻¹, N1 = 3.05 kg N ha⁻¹, N2 = 6.1 kg N ha⁻¹, N3 = 12.2 kg N ha⁻¹, N4 = 24.4 kg N ha⁻¹.
Figure 4.3. The effect of nitrogen rates on the visual assessment score of creeping bentgrass color 2, 4, 6, 8, 10, and 12 weeks after initial treatment in a) 2014 and b) 2015.

1 Means with the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.

2 Nitrogen treatments: N0 = 0 kg N ha\(^{-1}\), N1 = 3.05 kg N ha\(^{-1}\), N2 = 6.1 kg N ha\(^{-1}\), N3 = 12.2 kg N ha\(^{-1}\), N4 = 24.4 kg N ha\(^{-1}\).
Figure 4.4. The effect of nitrogen rates on the Digital Image Analysis of creeping bentgrass color 2, 4, 6, 8, 10, and 12 weeks after initial treatment in a) 2014 and b) 2015.

1 Means with the same letter are not significantly different ($P \leq 0.05$) according to the Fisher’s least significant difference (LSD) test.

2 Nitrogen treatments: N0 = 0 kg N ha$^{-1}$, N1 = 3.05 kg N ha$^{-1}$, N2 = 6.1 kg N ha$^{-1}$, N3 = 12.2 kg N ha$^{-1}$, N4 = 24.4 kg N ha$^{-1}$.
Figure 4.5. The effect of nitrogen rates on the grid counting of the void size 2, 4, 6, 8, 10, and 12 weeks after initial treatment in a) 2014 and b) 2015.

1 Means with the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.
2 Nitrogen treatments: N0 = 0 kg N ha\(^{-1}\), N1 = 3.05 kg N ha\(^{-1}\), N2 = 6.1 kg N ha\(^{-1}\), N3 = 12.2 kg N ha\(^{-1}\), N4 = 24.4 kg N ha\(^{-1}\).
Figure 4.6. The effect of nitrogen rates on the Digital Image Analysis of the void size 2, 4, 6, 8, 10, and 12 weeks after initial treatment in a) 2014 and b) 2015.

1 Means with the same letter are not significantly different (P ≤ 0.05) according to the Fisher’s least significant difference (LSD) test.

2 Nitrogen treatments: N0 = 0 kg N ha⁻¹, N1 = 3.05 kg N ha⁻¹, N2 = 6.1 kg N ha⁻¹, N3 = 12.2 kg N ha⁻¹, N4 = 24.4 kg N ha⁻¹.
Figure 4.7. Regression of the NDVI of creeping bentgrass by time under different nitrogen rates in 2014.

\[ y = -0.0007x^2 + 0.0273x + 0.4805 \quad R^2 = 0.9881 \]
\[ y = -0.0013x^2 + 0.0341x + 0.4879 \quad R^2 = 0.9961 \]
\[ y = -0.0021x^2 + 0.0434x + 0.4799 \quad R^2 = 0.9984 \]
\[ y = -0.0028x^2 + 0.0525x + 0.4977 \quad R^2 = 0.9953 \]
\[ y = -0.0038x^2 + 0.0658x + 0.4878 \quad R^2 = 0.9867 \]
Figure 4.8. Regression of coefficient-A under by nitrogen rates in 2014.

\[ y = -0.0008x - 0.0006 \]

\[ R^2 = 0.9928 \]
Figure 4.9. Regression of coefficient-B under nitrogen rates in 2014.

\[ y = 0.0095x + 0.0255 \]
\[ R^2 = 0.9862 \]
Figure 4.10. Regression of the grid counting of the void size by time under different nitrogen rates averaged from 2014 and 2015.
Figure 4.11. Regression of K under by nitrogen rates.

\[ y = -0.1886x - 5.6229 \]

\[ R^2 = 0.9935 \]
Discussion

Three field experiments were conducted from October 2013 to July 2015 at two different location in Columbus, Ohio to meet three major research objectives. In the first field experiment, the objective was to determine the interaction between methiozolin, nitrogen rates and nitrogen application frequency on annual bluegrass control and creeping bentgrass recovery in the spring after a successful methiozolin fall control program. Four nitrogen rates (0, 6.1, 12.2, 24.4 kg ha$^{-1}$) were applied at three different frequencies (once per month, twice per month, four times per month) and two spring methiozolin treatments (0, 0.53 kg a.i. ha$^{-1}$) applied every other week on an area which was uniformly treated with three applications of methiozolin at the rate of 0.53 kg a.i. ha$^{-1}$ starting October in the previous year. The results indicate that there was no significant interaction between methiozolin, nitrogen rates and fertilizing frequency. There was a significant interaction between nitrogen rates and fertilizing frequency on creeping bentgrass color. Among all the nitrogen rates and fertilizing frequencies, the 24.4 kg N ha$^{-1}$ every two weeks and the 12.2 kg N ha$^{-1}$ every week were the best for creeping bentgrass green-up, color and recovery into voids in a normal spring. Under warmer spring weather, less nitrogen was needed to improve color and bentgrass recovery. Also, the higher nitrogen rates increased the potential for unacceptable burn for a few weeks. Methiozolin treatment in the spring had a negative effect on both creeping bentgrass color and recovering rate into voids.
However, spring methiozolin also provided a subsequent control on the annual bluegrass population after the fall methiozolin treatments.

The objectives of the second field experiment were to determine the interaction between methiozolin rates and nitrogen rates on annual bluegrass control and creeping bentgrass surface quality in the spring. Four methiozolin rates (0, 0.53, 0.80, 1.06 kg ha\(^{-1}\)) and three nitrogen rates (6.1, 12.2, 24.4 kg N ha\(^{-1}\)) were tested for their effects on creeping bentgrass color, annual bluegrass color, and the annual bluegrass population. There was a significant negative effect of higher methiozolin rates on creeping bentgrass color, but the lower color ratings of creeping bentgrass caused by high methiozolin rates was not detected in the warmer spring weather of the second year. Higher methiozolin rates also had significant effects on the discoloration of annual bluegrass and a decrease in the annual bluegrass population. This indicates that the higher methiozolin rates did have better control over annual bluegrass compared to the protocol rate (0.53 kg a.i. ha\(^{-1}\)) in the spring. The color of both creeping bentgrass and annual bluegrass increased significantly with higher nitrogen rates. Instead of promoting annual bluegrass health and weakening the control efficiency of methiozolin, higher nitrogen rates actually encouraged creeping bentgrass more than annual bluegrass under methiozolin treatments to achieve better annual bluegrass control.

The third study was conducted to further study the effects of methiozolin and nitrogen rates on the color and lateral growth rate of creeping bentgrass in the spring. Two methiozolin rates (0, 0.53 kg a.i. ha\(^{-1}\)) and five nitrogen rates (0, 3.05, 6.1, 12.2, 24.4 kg N ha\(^{-1}\)) were both applied four times at two weeks intervals on a USDA ‘Penncross’
creeping bentgrass green at the Ohio State University Turfgrass Research and Education Facility, Columbus, Ohio. There was a negative but not statistically significant effect of the 0.53 kg a.i. ha$^{-1}$ methiozolin rate on the color and lateral growth of creeping bentgrass in the spring. The differences in creeping bentgrass color and lateral growth were mainly caused by nitrogen rates. The greatest color difference among nitrogen rate treatments occurred at six to eight WAIT. The regression of the NDVI of creeping bentgrass indicated that a higher nitrogen rate leads to faster green-up speed and higher maximum green color that creeping bentgrass was able to achieve than lower nitrogen rates in the spring. According to the regression of the grid counts of the void size, the lateral growth rate of creeping bentgrass was constant through time and was only influenced by the nitrogen rate. There was a directly proportional relation between nitrogen rates and creeping bentgrass lateral growth rate.

These results are similar to other research findings reported for spring applications of methiozolin on annual bluegrass control and creeping bentgrass safety. A field study conducted by Askew and McNulty (2014) on three creeping bentgrass putting greens in Virginia from 2009 to 2010 found that a single application of methiozolin at the rate of 0.5 kg ha$^{-1}$ and 0.75 kg ha$^{-1}$ as a pre-emergence herbicide application slowly suppressed annual bluegrass by controlling seedling development from seed. In the first three months after the spring-methiozolin application, there was 25% less annual bluegrass in the methiozolin treatments than the no methiozolin treatments. They also found that methiozolin had suppressed 85% to 87% of the annual bluegrass seed heads in the spring which matches other reports about the seedhead suppression with methiozolin (Koo et al., 2013).
Additionally, among all the treatments in the second and third field experiment, there was no noticeable phytotoxicity or discoloration on the creeping bentgrass caused by any methiozolin treatment or nitrogen treatments during the entire experimental period over the two years. There were also no injury or any negative effects on the NDVI of creeping bentgrass caused by methiozolin at any rates reported by Askew and McNulty’s (2014).

In this research, the color measurements as determined by NDVI, green index and digital image analysis were very similar to each other. However, visual assessment ratings tended to reflect the color/quality ratings at a higher significant level in the ANOVA test than other methods. Nitrogen treatments effects, especially on creeping bentgrass color, had less differences among rates in 2015 compared to 2014. This was probably because the experiment started one week later in 2015 than 2014 resulting in possibly less negative effects from cold temperature on potential phytotoxicity/discholoration of methiozolin on creeping bentgrass. Also a couple of warmer days from the end of April to early May in 2015 helped with the spring green-up of creeping bentgrass which leaded to less need for nitrogen. This all leaded to higher creeping bentgrass color ratings with lower nitrogen rates in 2015 compared to 2014.

Annual bluegrass population and percent voids coverage measurements cannot be determined by only the visual assessment or grid counting alone. Both methods have their limitations in presenting the changes of percent voids coverage. Visual assessment was more efficient in showing the relative differences between treatments, but not representative to the absolute value. The grid counting was more representative to the
absolute value. However, there were limitations of its coverage to the tested area and sometimes it cannot distinguish the voids caused by thinning creeping bentgrass or by declined annual bluegrass. In this study, both the results from grid counting and visual assessment were taken into consideration for the final conclusion of annual bluegrass population and voids coverage results. Digital image analysis can be a solution to this problem by measuring the exact number of target areas. However, the DIA was not used for annual bluegrass population measurement in this study due to technical difficulties.

For future research, a laboratory experiment would be helpful to determine the translocation and metabolism of methiozolin as influenced by nitrogen within the annual bluegrass plant to further understand the physiological mechanism of methiozolin within the plant. Also, the effects of temperature and temperature change, especially the low temperature and high to low temperature fluctuation, on the efficiency of methiozolin control on annual bluegrass and creeping bentgrass safety need to be further studied for better understanding of this promising selective herbicide on annual bluegrass control. In this research, there was some linear relationship determined between nitrogen rates and creeping bentgrass color and lateral growth rate. A series of nitrogen rates with wider range and less intervals can be tested for longer periods of time in the future to develop a more detailed and accurate model for creeping bentgrass color and lateral growth influenced by nitrogen rates in the spring.
References


Kane, R. and L. Miller. 2003. Field testing plant growth regulators and wetting agents for annual bluegrass seedhead suppression. USGA Green Section Record. 41:721-726.


Appendix A: Annual Bluegrass Declining after Fall Methiozolin Applications

In project 1, the entire experiment area was pre-treated with three applications of methiozolin at the rate of 0.53 kg a.i. ha\(^{-1}\) at two-week intervals in the fall. The fall applications of methiozolin were initialacted on Oct 2 and Sep 24 in 2013 and 2014, respectively. Two weeks after the first application, discoloration started to shown on annual bluegrass in the treated area. The discoloration continued to the next spring until annual bluegrass tissue started to die back, leaving voids over the putting green surface in the fall methiozolin treated area. Under these circumstances, spring methiozolin and no spring methiozolin along with nitrogen rates and fertilizing frequencies were tested to determine the effects of spring methiozolin on annual bluegrass surrpression and creeping bentgrass recovery and also the effects of different nitrogen application strategies on creeping bentgrass green-up speed and recovery into the voids left by the fall methiozolin applications.

Photos below show the discoloration of annual bluegrass after fall methiozolin applications and voids over the testing area in the next spring.
Figure A1. Discoloration of annual bluegrass a) 23 days, b) 51 days, and c) 74 days after the initial methiozolin application in the fall of 2014.
Figure A2. Area without methiozolin applications in the fall (left) compared with area treated with 3 applications of 0.53 kg a.i. ha\(^{-1}\) methiozolin at two-week intervals (right) 117 DAIT (01/19/15) in the spring of 2015.
Appendix B: Light Box Photos
Figure B1. Light box photos showing the effects of methiozolin and nitrogen rates on creeping bentgrass color and lateral growth from 0 WAIT to 10 WAIT in 2014.