MITIGATION OF INDAZIFLAM PHYTOTOXICITY IN BERMUDAGRSS TURF IN SAND BASED ROOT ZONES

By

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MITIGATION OF INDAZIFLAM PHYTOTOXICITY IN BERMUDAGRSS TURF IN SAND BASED ROOT ZONES

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In the United States, bermudagrass is the most used turf type for golf courses. Turf managers apply pre-emergence herbicides with the objective of obtaining season-long weed control in golf course and secondary turf areas. There are many factors that affect the persistence of soil applied pre-emergence herbicides. These factors include soil, climatic conditions, and herbicidal properties, whereas all of these strongly interact with each other. There are three main modes of action of pre-emergence applied herbicides that have been effective in controlling grass and broadleaf weeds in bermudagrass turf - Mitotic Inhibitors (MTI), Protoporphyrinogen IX Oxidase Inhibitors (PPO), and Cellulose Biosynthesis Inhibitors (CBI); however, some classes of herbicides cause detrimental effects on root growth and overall turf health.

Indaziflam (N-[1*R*,2*S*]-2,3-dihydro-2,6-dimethyl-1*H* -inden-1-yl]-6-[(1*R*)-1-fluoroethyl]-1,3,5-triazine-2,4-diamine) was registered for use in the turf market in 2012 by Bayer Crop Science LP. 2012. Previous research has concluded that indaziflam provides season long weed control for weeds such as crabgrass species (*Digitaria* spp.), annual bluegrass (*Poa annua L.*), and goosegrass (*Eleusine indica L.)* with equal or better control than older herbicides like prodiamine, dithiopyr, and oxidiazon. However, there are concerns with this herbicide class

having similar negative effects to turf roots as have been noted with MTI herbicides such as dithiopyr and prodiamine. Research conducted with indaziflam has shown this to be true; however, most of the research has been conducted in controlled conditions. Jones et al. (2015) suggested that additional studies need to be conducted to conclude the potential for mitigation of phytotoxic effects observed from applications of indaziflam. Previous studies have shown the potential for organic matter remediation to reduce phytotoxicity from indaziflam applications in controlled conditions, but note that field experiments need to be evaluated before proper recommendations can be made on the potential to reduce this phytotoxicity that has been observed.

The objective of this research was to observe if there was phytotoxic response from various rates of indaziflam in bermudagrass turf in sand based root zones. In addition could this phytotoxicity be mitigated by a product that could increase organic content in the soil mixed with indaziflam. In 2014 indaziflam was tested in a mixture with a high organic product from Harrell's, LLC. with the trade name EarthMAX™. Taking into considerations experiments conducted by Jones et al. (2013) and Schneider et al. (2015), it was assumed there was potential for similar results in a field setting if indaziflam could be mixed and applied with a product that would promote increased organic carbon and CEC in the soil medium and promote nutrient uptake by bermudagrass turf. Research was conducted in the summer of 2014 at the University of Florida Fort Lauderdale Research and Education Center (Fort Lauderdale, FL). 'Tifway' (Cynodon dactylon X C. Transvaalensis L.) bermudagrass was used in the experiment grown on a sandy native soil. This experiment demonstrated the ability of EarthMAX™ to reduce these phytotoxic effects caused by sandy soils.

INTRODUCTION: SIGNIFICANCE AND RATIONALE

(PROBLEM STATEMENT)

INTRODUCTION

In the United States, bermudagrass is the most widely used plant species on golf courses (Lyman et. al., 2007). Turf managers apply pre-emergence herbicides with the objective of obtaining long-term preventative weed control in golf course and secondary turf areas (Brosnan et al., 2011; Johnson et al., 1997; Yelverton and McCarty, 2001). There are many factors that affect the persistence of pre-emergence herbicides in the soil, although most fall into three categories (Grey and McCullough, 2012; Hixson et al., 2009; Ohmes et al., 1999; Shaner et al., 2008; Szmigielskiet al., 2009).

- Soil Factors
- Climatic Conditions
- Herbicidal properties

Additionally these three categories strongly interact with each other (Curran, 2001; Hager and Dawn, 2007).

SOIL FACTORS

The soil factors that affect herbicide persistence are Physical, chemical, and microbial (Curran, 2001; Hager and Dawn, 2007).

PHYSICAL

Physical factors include soil composition, which includes soil texture and organic matter (OM) content. These factors in turn affect herbicide fate through adsorption, leaching and volatilization. Generally, soils with higher clay and/or OM content have greater potential for herbicide persistence (Hager and Dawn, 2007), however may negatively impact herbicide efficacy (Blumhorst et. al., 1990). Over the last several decades, a number of research experiments have been conducted to attempt to correlate these specific factors to herbicidal activity. Presence of soil OM has been shown to correlate positively to herbicide persistence (Blumhorst et. al., 1990), as well as overall soil texture (Alonso et al., 2011; Jones et al., 2013). Harrison et al. (1976) and Peter and Weber (1985) found that although soil OM is a key factor in herbicidal activity, and other factors such as soil pH, clay content, water holding capacity, and cation exchange capacity (CEC) are important as well.

CHEMICAL

Chemical factors include pH, CEC, and nutrient levels. Some herbicides are affected more intensely by one factor or another. For example, triazine urea herbicides are particularly affected by pH. Lower amounts of triazine ureas are bound to the soil colloids at higher soil pH. As a consequence, at high soil pH, the traizines ureas will be present in soil solution, thus subject to leaching and more available for plant uptake (Curran, 2001; Hager and Dawn, 2007). Blumhorst et al. (1990) found herbicide efficacy was negatively impacted by CEC, and with humic matter and OM contents. As CEC, OM, and humic matter increased, increased rates of herbicide were needed to achieve 80% weed control. Additionally, some members of the sulfonyl urea herbicide group can be persistent in higher pH soils due to decreased rates of chemical breakdown. In contrast, low soil pH affects the persistence of domazone, imaziquin and imazethapyr herbicides (Hager and Dawn, 2007). As the pH drops below 6.0 these chemicals are more adsorbed to the soil colloid and their availability is reduced to soil microbes which reduces degradation and increases persistence in the soil (Curran, 2001).

MICROBIAL

Microbial factors relate to the type and concentration of soil microorganisms present (Hager and Dawn, 2007). Microorganisms utilize OM, minerals, and substances in the soil as a food source and are fundamental to soil structure, formation, and plant nutrient availability (Sylvia et al., 2005). Research has shown that herbicides added to the soil environment can increase soil induced respiration (SIR). Additionally, each herbicide may affect the soil microbial communities in different ways. There may be differential effects on fungal and bacteria groups and promote growth of one over the other (Wardle and Parkinson, 1990). As a consequence, the herbicidal effect on different soil microbial communities may negatively impact the mineralization capacity of the soil (Anderson and Domsch, 1990) and could ultimately impact plant nutrient availability and uptake.

Furthermore, soil microbial activity has a big impact of the degradation of the chemical structure as the microbes feed on herbicides in the soil. Microbial activity varies widely for many herbicides in the soil. For example, the soil microbial degradation of 2, 4-D occurs more rapidly than the microbial degradation of atrazine (Hager and Dawn, 2007).

CLIMATIC CONDITIONS

Climatic variables that affect herbicidal degradation include sunlight, moisture, and temperature.

Sunlight is an important factor in the degradation of herbicides. Photodegradation, or decomposition by sunlight has been reported for many herbicides, including dinitroanilines (Hager and Dawn, 2007). They may be lost when surface-applied if they remain for an extended time without irrigation or rainfall. This is the primary reason for soil incorporation of many pre-emergence herbicides applied through irrigation (Zimdahl and Gwynn, 1977).

The chemical properties of herbicides affect their persistence in conjunction with the other factors above (Soil and Climatic). Not all herbicides react the same in the soil; therefore, there are several different properties than can affect their efficacy and persistence within that environment. The most important properties include water solubility, soil adsorption, and vapor pressure, as well as susceptibility to microbial degradation. Water solubility will affect how readily herbicides will leach within a given soil environment (Hager and Dawn, 2007; Curran, 2001). As water solubility increases, the herbicide will more readily dissolve and increase the potential for leaching and downward movement through the soil environment. The other factor which will influence herbicide leaching is how well the herbicide will adsorb to soil colloids. Both soil water and soil texture interact to affect the tendency of an herbicide to leach completely through the soil or into the root zone of a plant, where it may then interface with the plant itself (Curran, 2001; Simmons, 2006).

Vapor pressure, another important factor, affects how fast the chemical will change from a liquid phase to a gas phase and potentially volatilize. Herbicides with high volatility will need to be incorporated into the soil to be effective and are less likely to persist in the soil. Chemical decomposition also depends on a number of factors including hydrolysis, oxidation, and reduction. The capacity of these processes to occur for any given herbicide depend greatly on soil type, climatic conditions, and soil microbial activity, which together greatly affect the overall decomposition of herbicides (Curran, 2001; Hager and Dawn, 2007).

HERBICIDE BACKGROUND

There are three primary modes of action for herbicides that have been used effectively in controlling grass and broadleaf weeds in bermudagrass turf (Brosnan, 2011; Venner et al., 2013). These include mitotic inhibitors (MTI), protoporphyrinogen oxidase inhibitors (PPO), and cellulose biosynthesis inhibitors (CBI) (Senseman, 2007). MTI and CBI class of herbicides mode of action have been found to have a negative impact on the health of the bermudagrass roots (Brosnan et al., 2011, Fishel and Coats, 1994). However, the PPO mode of action does not affect the roots of plants and is absorbed through foliar uptake (Jones et al., 2013).

MTI herbicides include chemicals such as prodiamine, pendimethalin, and dithiopyr. MTI herbicides disrupt the production of the microtubule protein, tubulin, in susceptible species (Senseman, 2007) and do not translocate in the plant (Ross and Childs, 2015). These herbicides have very low leaching potential due to their low water solubility, but are subject to photo-degradation and volatilization, therefore they need to be incorporated into the soil to maintain efficacy (Ross and Childs, 2015).

CBI herbicides used in turfgrass include indaziflam and isoxaben. CBI herbicides affect different sites within the cellulose biosynthetic pathway. Sabba and Vaughn (1999) concluded that certain CBI herbicides prevent uridine dophosphate (UDP) -glucose pools from producing the cellulose required to strengthen and fuse the cell plate with the parent cell wall during mitosis.

PPO inhibitors used in pre-emergence herbicide applications to bermudagrass are oxidiazon and flumioxazin. PPO is an enzyme in the chloroplast that oxidizes protoporphyrinogen IX (PPGIX) to produce protoporphyrinogen IX (PPIX), which is an important molecule for chlorophyll and heme biosynthesis (Anonymous, 2015). PPO inhibitors have limited translocation in the plant and usually burn plant tissues within hours of exposure (Anonymous, 2015).

Annual weeds in bermudagrass turf are often controlled by pre-emergence applied herbicides. However, some classes of these herbicides cause detrimental effects on root growth and overall health of the turf (Brosnan et al., 2011; Fishel and Coats, 1993). It has been documented that applications of MTI and CBI herbicides can have a negative effect on bermudagrass root growth as well as foliar injury (Jones et al., 2015). Several researchers have observed reductions in root weight and negative effects on root morphology following treatments of prodiamine and dithiopyr, both MTI herbicides (Bhowmik and Bingham, 1990; Ferrell et al., 2003; Fishel and Coats, 1993,). Heim et al. (1998) demonstrated that CBI herbicides affect roots differently than MTI herbicides observing malformation of the root epidermis near the tip in response to MTI herbicide applications giving the appearance of bubbles and that CBI herbicide treatments maintained the root epidermis, but caused elongated swollen root hairs.

INDAZIFLAM PHYTOTOXICITY

Indaziflam (N-[1*R*,2*S*]-2,3-dihydro-2,6-dimethyl-1*H* -inden-1-yl]-6-[(1*R*)-1-fluoroethyl]-1,3,5-triazine-2,4-diamine) was registered for use in the turf market in 2012 by Bayer Crop Science LP (Myers et al., 2009). The herbicide is part of the alkaline family and is a CBI herbicide. Indaziflam has shown to be an effective season long pre-emergence herbicide with a half-life of 150 days (USEPA, 2010). As a weak acid (pK4 = 3.5), indaziflam has been shown to adsorb to soil colloids within a couple hours. Additionally, indaziflam demonstrated low mobility in soil based on sorption and desorption studies done. These studies were conducted in various soil textures ranging from sandy to clay, soil pH ranging from 5.4 to 8.3 and soil organic carbon content of 0.5 to 2.52% (Alonso et al., 2011). Alonso et al., (2011) found that indaziflam adsorption was correlated with soil organic carbon ranging from 0.5% to 2.5% and clay content ranging from 7 to 65%. Another study confirming adsorption properties of indaziflam was a simulated rainfall study in a Florida Candler Soil (hyperthermic, uncoated Lamellic Quartzipsamments) (Jhala and Singh, 2012). Indaziflam leached, on average, 12 cm, following 5 cm ha^{-1} of rainfall and 27 cm following 15 cm ha^{-1} of rainfall, and regardless of irrigation amount, no leaching was found beyond 30 cm soil depth.

Previous research has concluded that indaziflam provided season-long weed control for weeds such as crabgrass (*Digitaria* spp.), annual bluegrass (*Poa annua L.*), and goosegrass (*Eleusine indica L.*) with control equal or better than other herbicides like prodiamine, dithiopyr, and oxidiazon (Brosnan, 2011). However, there were concerns with this herbicide class having similar negative effects to turf roots as noted with MTI herbicides such as dithiopyr and prodiamine, which disrupt microtubule assembly and induce abnormal root formations (Fishel and Coates, 1994).

Although indaziflam has a low propensity for downward mobility (Alonso et al. 2011), Jones et al. (2013) conducted a study to determine turf responses of applications of indaziflam and prodiamine in two different soils (sand and silt loam). The authors found that indaziflam applications in sand root zones with no organic matter caused more foliar injury than those in silt loam root zones. Prodiamine exhibited little to no foliar injury in either soil type. Both indaziflam and prodiamine reduced root length density by more than 68% in a study carried out by Jones et al. (2013). Moreover, Jones et al. (2013) reported a reduction in root length density in both treatments of indaziflam and prodiamine and Fishel and Coates (1994) observed that prodiamine did not have an effect on the total number of roots, but resulted in the formation of abnormal root structures such as lack of secondary root formation and root swelling. In sand, Schneider et al. (2015) observed nearly complete suppression of secondary root formation in the upper 10 cm of the roots treated with indaziflam and found significant differences in visual assessment of foliar injury, shoot and root biomass, and root morphology in soil with or without organic matter present. This is similar to other research that has been conducted observing root effects of plants treated with MTI herbicides (Fishel and Coats, 1994). In a study conducted by Jones et al. (2015), indaziflam, isoxaben, and prodiamine reduced root mass more than oxadiazon. Additionally, roots of plants treated with indaziflam were darker in color than plant roots treated with prodiamine; however prodiamine treated plants showed greater signs of clubbed root tips than did indaziflam, thus solidifying the idea that MTI and CBI herbicides cause similar effects in root color changes but differential effects on bermudagrass root morphology. Heim et al. (1998) also found differential effects on root morphology where plants following MTI herbicide applications had abnormality of the root epidermis and no lateral roots, and plants treated with CBI herbicide applications had no effect on the root epidermis, but a negative effect on root hairs. Furthermore, in the study conducted by Jones et al. (2015), indaziflam and isoxaben showed bermudagrass foliar injury while prodiamine resulted in minimal foliar injury. Additionally, foliar dry weight was reduced with applications of indaziflam while applications of oxidiazon were not different from the untreated control and applications of prodiamine and isoxaben were inconsistent among the two studies conducted pertaining to foliar injury (Jones et al., 2015).

Considering most nutrients are absorbed through the roots (Bowling, 1976), negative effects on root morphology, such as clubbing and reduced root mass, may impact uptake and utilization of nutrients within the plant and can potentially explain the foliar symptoms observed in research conducted by Jones et al. (2015). The results from Jones et al. (2013) suggest that herbicides may affect the uptake and translocation of certain nutrients differently in bermudagrass plants. Applications of prodiamine, isoxaben and indaziflam reduced phosphorus (P), sulfur (S), and potassium (K) content in foliar tissue vs. the untreated control while oxidiazon had no effect (Jones et. al., 2015). Additionally, treatments with indaziflam also reduced magnesium (Mg) and manganese (Mn) in foliar tissue and oxidiazon had no effect on foliar nutrient contents. Mn and Mg are involved light reactions of photosynthesis (Taiz and Zeiger, 2015); therefore, reduced amounts of these nutrients in the foliar tissue could overall health of the plant which was consistent with observations in the indaziflam applications. Jones et al. (2015) suggested that additional studies need to be conducted to conclude the potential for mitigation of phytotoxic effects seen by indaziflam applications.

MITIGATION OF INDAZIFLAM PHYTOXICITY

Soils that are high in clay content generally have a higher adsorption rate of applied herbicides. This may decrease the concentration of the herbicide available in soil solution, thus reducing the risk of root absorption and potential phytotoxicity (Ferrell et al., 2003; Grey et al., 1997). Additionally, organic matter (OM) has been shown to reduce herbicide activity and thus may reduce injury to turfgrass if present in the root zone (Harrison et al., 1976). Ferrell et al. (2003) found that both soil adsorption and plant absorption of sulfentrazone (pK4 = 6.6) was affected by soil pH. However, Szmigielski et al. (2009) concluded that soil organic carbon was the single most important factor affecting the phytotoxicity of sulfentrazone. Similarly, Hixson et al. (2009) found that OM influenced the adsorption of simazine (pK4 = 1.6). Schneider et al. (2015) observed when peat moss was added to sand reduced phytotoxicity in hybrid bermudagrass from indaziflam applications compared to bermudagrass grown in unamended sand. Therefore, potential injury from indaziflam may be reduced in soils with greater organic carbon and clay content. Research on the effect of OM and clay content in the soil influencing phytotoxic effects of indaziflam applications in bermudagrass turf are limited and further research needs to be conducted to evaluate their use to reduce negative effects from applications (Schneider et al., 2015). Drohen et al. (1997) concluded that the use of sludge based fertilizer increased foliage yield, turf quality, and density in Kentucky bluegrass yet did not decrease weed control for crabgrass with pendimethalin. Jones et al. (2013) observed that soil organic carbon content and application rate affect indaziflam injury to hybrid bermudagrass grown in sand-based root zones. Furthermore, they inferred that cation exchange capacity (CEC) affects indaziflam activity in sand culture to a greater extent than soil pH increasing organic carbon from 0.000 to 0.007 kg kg^{-1} reduced injury to foliage and roots with indaziflam at 52.5 g ha^{-1}. Alonso et al. (2011) suggested that the triazinediamide group in the indaziflam chemical structure may be interacting with the OM content of the soil to reduce overall concentration of indaziflam in soil solution, thus reducing the effect it will have on plant roots.

OBJECTIVES AND HYPOTHESIS

The objective of this research was to observe if there was phytotoxic response from various rates of indaziflam in bermudagrass turf in sand based root zones. In addition could this phototoxicity be mitigated by a product that could increase organic content in the soil mixed with indaziflam. Previous studies have suggested the potential for OM remediation to reduce phytotoxicity from indaziflam applications in controlled environments, but noted that field experiments needed to be conducted before proper recommendations could be made on the potential to reduce phytotoxicity (Jones et al. 2013, Jones et al. 2015, and Schneider et al. 2015). In 2014, indaziflam was tested at the University of Florida Fort Lauderdale Research and Education Center (Fort Lauderdale, FL) as a mixture with, EarthMAX™ (EM), a liquid organic product from Harrell's LLC. Taking into consideration experiments conducted by Jones et al. (2013) and Schneider et al. (2015), it was assumed there was potential for similar results of phytotoxicity to bermudagrass and remediation in a field setting if indaziflam could be mixed and applied with a product that would promote increased organic content and CEC in the soil.

METHODOLOGY (STUDY AREA, DESCRIPTION OF DATA AND METHODS)

EM was selected as an organic material to mix with indaziflam to assess the potential to mitigate potential phytotoxic effects of applications at various rates. Harrell's LLC makes the following claims about EM on their website (Anonymous b, 2015).

"Harrell's EarthMAX™ is intended for use on trees, shrubs, grass, vegetables, flowers, and crops. Applying EarthMAX™ to indoor and outdoor container plants may aid in micronutrient uptake and increased water retention. EarthMAX™ provides trace minerals and soil biology with humic acids. When used as directed, EarthMAX™ is non-toxic and safe to use around people.

EarthMAX™

EarthMAX™ increases root growth and turf vitality, even under environmental stress.

Features:

- 100% Organic to USDA standards

- Contains high levels of humic and fulvic acid
- Provides all 16 essential elements required for optimal plant health in a readily available organic form
- Mycorrhizae and Saprotrophic Fungi
- Photosynthetic and naturally occurring bacteria, including *Bacillus subtilis*
- High carbon content
- Only biologically active humic acid available

Designed for these Benefits

- Provides balance to your soil structure and restores fertile soil conditions
- Does not leach
- Chelates nutrients including Ca, Mg and Fe
- Improves C.E.C.- helps hold nutrients in the root zone
- Diverse biological populations that colonize root systems and improve nutrient uptake
- Works with resident soil biology to enhance root growth and health. (Harrell's EarthMAX…, 2015)"

Therefore, based on the properties above, EM is believed to have potential to reduce phytotoxicity and increase turf quality when mixed with indaziflam when mixed with the product.

The research trial was conducted in the summer of 2014 at the University of Florida Fort Lauderdale Research and Education Center (Fort Lauderdale, FL). 'Tifway' hybrid bermudagrass was grown on a Hallandale fine sand (siliceous, hyperthermic lythic psammaquent). Plots measured 1 m x 2 m and treatments were arranged in a randomized complete block design with three rates of indaziflam, 16.22, 32.44, and 48.66 g ha^{-1}, with and without EM at 9.35 L ha^{-1} and each treatment was replicated four times. The treatments of indaziflam and EM correspond with labeled rates of each product for use in bermudagrass turf. Treatments were applied on May 25, 2014 with a carbon dioxide (CO^2) backpack sprayer with Teejet flat fan 110 degree angle with 45.7 cm spacing at 30psi and watered in immediately with 1.27 cm of irrigation. Plots were maintained with routine growing conditions, mowing at 1.5cm, 2 to 3 times per week during the study. Data were collected two times after application in 2014 on June 12th and July 2nd.

Ten days prior to the study, the site in Fort Lauderdale, FL had received a total of 2.67cm of rain (Table 2). During the study, the site received a total of 28.75cm of rain (Table 2). On average the site received 0.73cm daily rainfall and had 0.41cm of evapotranspiration; therefore, rainfall was in excess of daily plant needs providing a surplus of water to the soil and no irrigation was necessary during the trial (Table 2).

Plots were rated visually for quality on the standard 1 to 9 National Turfgrass Evaluation Program (NTEP) rating scale where 9 is the highest and 6 is the lowest acceptable rating. Plots were also rated visually for phytotoxicity using a 0 to 5 scale where 0 represents no phytotoxicity and 5 extreme phytotoxicity (Dead or brown turf) and 2 is minimally objectionable discoloration.

Analysis of variance (ANOVA) was performed using the PROC ANOVA Duncan's Multiple Range Test method (SAS Inst., 2003) for turf quality and phytotoxicity ratings.

RESULTS AND DISCUSSION

Overall the results of the study reveal a reduction in turf quality as rates of indaziflam increased compared to the untreated control and EM reduced the negative effect from indaziflam, but was only significant at the 32.44 g ha^{-1}. This agrees with the hypothesis of the author of the ability of an organic product mixed with indaziflam mitigate phytotoxic effects caused by the product.

Specifically, On the June 12, 2014 rating, ANOVA (Table 1) revealed a reduction in turf quality compared to the untreated control with indaziflam at 16.22 g ha^{-1} + EM at 9.35 L ha^{-1} , indaziflam at 48.66 g ha^{-1} + EM at 9.35 L ha^{-1}, indaziflam at 32.44 g ha^{-1} without EM, and indaziflam at 48.66 g ha^{-1} with and without EM at 9.35 L ha^{-1}. For phytotoxicity, ANOVA revealed a difference in phytotoxicity ratings with indaziflam at 32.44 g ha^{-1} without EM and indaziflam at 48.66 g ha^{-1} without EM. Within this rating date, it appears that EM proved to reduce phytotoxic effects when added to indaziflam at 9.35 L ha^{-1} with indaziflam at 32.44 g ha^{-1} and 48.66 g ha^{-1}; however, differences in turf quality were still present compared to the untreated control at both these rates with and without EM.

On the 2014 July 2nd rating, ANOVA (Table 1) revealed a reduction in quality compared to the untreated control with indaziflam at 32.44 g ha^{-1} without EM. Additionally, this same treatment produced phytotoxic effects that were different from the untreated control. All other treatments were not different than the untreated control within this rating date.

CONCLUSIONS

There are many soil and environmental factors that affect herbicide longevity, mobility, and uptake by plants (Hager and Dawn, 2007). Researchers have shown that these factors provide an environment where soil herbicide applications of MTI and CBI herbicides can have negative effects on bermudagrass turf grown in sandy soils (Brosnan et al., 2011, Fishel and Coats, 1994, Jones et al. 2015). This experiment demonstrated the ability of an organic product such as EM to reduce phytotoxic effects caused by indaziflam in sandy soils. Although the exact mechanism to reduce the phytotoxicity caused by indaziflam is unknown, further research would need to be conducted to determine which specific properties are actually causing this mitigating effect. Additionally, there is no published research on the EM and its effects in soil or on the physiology of the plant and or turfgrass.

Furthermore, this study was conducted for only one year. Multiple years of data are needed, on multiple soil textures, in various regions, to fully conclude the ability of EM to be used as an adequate product for the reduction of phytotoxic effects of indaziflam in bermudagrass. In addition, the purpose of this study was to determine injury mitigation from indaziflam, a key property not tested in the experiment was the effect EM may have on the efficacy of indaziflam for pre-emergence control of weeds in turfgrass. Further field experiments will need to be conducted to determine if EM can reduce injury from indaziflam application while maintaining efficacy on grassy and broadleaf weeds.

Although injury from higher rates of indaziflam might be overcome by mixing the product with EM, reduced herbicide rates may still be required to minimize the potential for phytotoxicity in low OM, sandy soils, that receive excessive rainfall. Future research exploring soil moisture interaction with soil texture will need to be conducted to know how the rainfall variable effects the interaction as well. The results of this study concur with other research conducted to determine the ability to reduce phytotoxic effects of indaziflam in bermudagrass in sandy soils.

Table 1. Effects of indaziflam and EarthMAX™ on visual quality and phytotoxicity of 'Tifway' Hybrid Bermudagrass (C. dactylon (L.) Pers. X C. transvaalensis Burtt-Davey, cv. Tifway) at the University of Florida Research and Education Center (Fort Lauderdale, FL) during 2014. Treatments were applied on May 25, 2014. Plots were rated visually for quality on the standard 1 to 9 National Turfgrass Evaluation Program (NTEP) rating scale where 9 is the highest and 6 is the lowest acceptable rating. Plots were also rated visually for phytotoxicity using a 0 to 5 scale where 0 represents no phytotoxicity and 5 extreme phytotoxicity (Dead or brown turf) and 2 is minimally objectionable discoloration.

Rate		June 12		July 02	
Indaziflam ($g\ ha^{-1}$)	EarthMAX™ ($L\ ha^{-1}$)	Quality (1-9)	Phytotoxicity (0-5)	Quality (1-9)	Phytotoxicity (0-5)
00.00	0.00	8.00a	0.50b	7.75a	1.13b
00.00	9.35	7.63a	0.50b	7.63a	1.50b
16.22	0.00	7.25ab	1.5ab	8.00a	1.25b
16.22	9.35	6.38bc	1.63ab	6.88ab	2.00ab
32.44	0.00	5.50cd	2.38a	5.75b	2.75a
32.44	9.35	7.00ab	0.75b	7.75a	2.13ab
48.66	0.00	4.88d	2.00a	6.63ab	2.13ab
48.66	9.35	6.25bc	1.63ab	7.50a	1.88ab
Critical Range		1.27	1.27	1.48	1.24

Table 2. Daily Temperature and Rainfall data for Fort Lauderdale, FL

		Temperature (F˚)		Rainfall (cm)		
Month	Day	Low[a]	High[a]	Daily[a]	Cumulative Total	ET (cm)
May	25	73	86	0.00	0.00	0.51
	26	73	86	0.00	0.00	0.58
	27	74	85	0.00	0.00	0.51
	28	76	87	0.00	0.00	0.48
	29	68	83	4.39	4.39	0.20
	30	73	86	0.00	4.39	0.48
	31	76	86	0.25	4.65	0.48
June	1	74	85	0.71	5.36	0.43
	2	74	81	1.12	6.48	0.23
	3	74	81	0.00	6.48	0.25
	4	73	81	0.51	6.99	0.25
	5	70	84	0.00	6.99	0.56
	6	70	89	0.00	6.99	0.56
	7	76	92	0.00	6.99	0.51
	8	72	88	3.71	10.69	0.28
	9	72	91	0.00	10.69	0.48
	10	72	87	0.33	11.02	0.33
	11	65	87	0.99	12.01	0.36
	12	32	89	2.79	14.81	0.38
	13	71	89	1.60	16.41	0.38
	14	70	88	0.03	16.43	0.41
	15	78	88	0.00	16.43	0.43
	16	77	86	0.00	16.43	0.58
	17	71	81	2.97	19.41	0.28
	18	74	83	0.38	19.79	0.30
	19	71	87	1.09	20.88	0.38
	20	71	87	1.37	22.25	0.33
	21	73	88	3.56	25.81	0.33
	22	71	91	0.08	25.88	0.43
	23	32	90	0.00	25.88	0.43
	24	75	90	0.00	25.88	0.48
	25	75	90	0.05	25.93	0.46
	26	74	89	0.00	25.93	0.41
	27	69	89	0.03	25.96	0.48
	28	75	89	0.10	26.06	0.46
	29	75	93	1.22	27.28	0.48
	30	74	91	0.00	27.28	0.46
July	1	74	88	0.66	27.94	0.25
	2	73	90	0.81	28.75	0.33
Average				0.74		0.41

[a]Based on data from http://fawn.ifas.edu/

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BIOGRAPHICAL SKETCH

Jason Hamilton Frank was born in 1982, in Deland, FL. He lived there until 2001when he graduated from Deland High School and was accepted to the University of Central Florida. He spent a year there as a business administration major before realizing he wanted to attend the University of Florida. He transferred to Daytona Beach Community College in August of 2002 and received his A.A. degree in July of 2003. He then transferred to the University of Florida in August of 2003 where he completed his B.S. in Turfgrass Science with a minor in Business Administration in December of 2005. He then went on to graduate school, also at the University of Florida and graduate with his M.S. in Horticulture Sciences with a minor in Agricultural and Biological Sciences in May of 2008. Upon graduation Jason accepted a 2nd assistant superintendent position at Royal Poinciana Golf Club in Naples, FL where he worked for 3 years while working toward his Master of Business Administration (M.B.A) at Florida Gulf Coast University. He was then hired by Bayer Crop Science LP as an Area Sales Manager in Southwest Florida in October of 2010 and completed his MBA at Florida Gulf Coast in May of 2011. In January of 2012 He started the Professional Masters of Soil and Water Science at the University of Florida while still working at Bayer Crop Science LP and was promoted to Key Account Manager at Bayer. Upon graduation, Jason will continue his career at Bayer Crop Science LP.