Summer-induced iron chlorosis on Kentucky bluegrass turf

by

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TABLE OF CONTENTS

GENERAL INTRODUCTION

Kentucky bluegrass (*Poa pratensis* L.) is the most commonly used turf species in the climatic zones suited for cool-season grasses. It is used widely because it has many characteristics that are desirable for a turf species including: it is a perennial, has rhizomes, tolerates mowing, establishes well from seed, and can maintain a dense turf (Christians, 2007). Kentucky bluegrass is used in a wide range of areas including home lawns, parks, cemeteries, sports fields, and golf courses.

Performance demands on turfgrass species are leading to changes that affect plant nutrition. Sand-based root zones are being used to replace native soils because of their physical characteristics. This helps reduce compaction problems and can lead to better drainage. Sand-based root zones typically have a lower cation exchange capacity (CEC) than a finer textured soil. Due to the low CEC and low organic matter of sand-based root zones, nutrient retention becomes problematic (Carrow et. al., 2001). Having adequate nutrients in the soil is important for maintaining healthy turf (Happ, 1995). If there is a deficiency or toxicity, turf growth, health, and quality are all compromised (Beard, 1973).

There are 17 essential nutrients required for plant growth. There are nine macronutrients (carbon, hydrogen, oxygen, phosphorus, potassium, sulfur, calcium, and magnesium) and eight micronutrients (iron, boron, manganese, copper, zinc, molybdenum, chlorine, and nickel). Extensive research has been conducted on the macronutrients, especially nitrogen, phosphorus, and potassium. The most researched micronutrient is iron. Iron is the fourth most abundant mineral in the earth’s crust (Krauskopf, 1972) and is the most abundant micronutrient in surface soils (Fageria et. al., 2002). Despite its abundance, iron deficiency is still a common occurrence in turfgrass. Much is known about iron’s role in the plant and how iron absorbed up by the plant (Favre et. al, 2002; Graham and Stangoulis, 2003). Many of the environmental conditions that commonly generate iron deficiency are known.

A deficiency of iron in plants causes chlorosis. This is a yellowing of plant tissue that is typically green in color. Iron is immobile in the plant and chlorosis usually appears as interveinal chlorosis on new growth. The green color in plants is caused by chlorophyll. Iron is not part of the chlorophyll molecule, but is involved in the synthesis of chlorophyll. Without iron, chlorophyll production ceases and the plant loses its green color. Along with being a cofactor in chlorophyll synthesis, iron is involved in the function of ferredoxin and cytochromes.

Soil pH can have a large effect on Fe availability because at an alkaline pH, iron is made insoluble in the soil (Brady and Weil, 2002). Iron is present in the soil solution in two forms, ferrous iron (Fe^{2+}) and ferric iron (Fe^{3+}). The Fe^{2+} is more soluble, but Fe^{3+} is the form that is more abundant in surface soils due to the oxidizing environment. Along with alkaline conditions, calcareous soils are likely to have low iron solubility (Chen and Barak, 1982; Rutland and Bukovac, 1971; and Boxma, 1972). Calcium carbonate ($CaCO_3$) in the soil leads to the formation of bicarbonate (HCO_3^-) which favors the formation of Fe^{3+}.

Iron fertilization can be difficult in high pH soils. By applying a non chelated iron source such as iron sulfate ($FeSO_4$) or ferric chloride ($FeCl_3$), the iron goes into solution as Fe^{2+} or Fe^{3+} and rapidly precipitates out. To keep the iron in solution compounds called chelates are used. The word chelate comes from the latin word for claw. Chelates are organic molecules that bind to metal ions. There are many chelating agents both natural and synthetic. Chelates are pH dependent and their efficacy is affected by pH. Studies show that some chelates work well at a high pH while others are almost useless at the same pH. Garcia-Mina et al. (2003) rated the following chelating agents and fertilizers for how long they kept iron in solution. The materials listed from longest solubility to shortest are Fe-EDDMA, Fe-EDDHA, Fe-EDDCHA, Fe-EDDHSA, Fe-DTPA, Fe-EDTA, and ferrous sulfate.

Minner and Butler (1984) found that application of iron fertilizers increased color of Kentucky bluegrass 11 days after application, but had no effect on color a year later. In other plants, like soybean, it has been suggested that the best way for treating iron chlorosis is through cultivar selection for resistant varieties (Lingenfelser et. al., 2005; and Goos and Johnson, 2000). This may be a practical approach for turf species as Harivandi and Butler (1980) noticed cultivar differences in iron chlorosis of Kentucky bluegrass.

Chlorosis of turf has always been common for grass grown on high pH soils. In the last ten years, however, we have observed a new phenomenon. We are seeing summer-induced chlorosis which is a yellowing of turf in the summer, but not in the spring and fall. Summer-induced chlorosis is widespread and has been observed in multiple countries on golf courses, home lawns, and sport fields. While summer-induced chlorosis generally appears on sand based root zones, it has also been seen on finer textured soils.

In 1999, a sand pad was constructed at the Iowa State University horticulture research station. Calcareous sand with a pH of 8.2 was spread to a depth of 20 cm. Summer-induced chlorosis has been observed annually on this site in mid to late summer. Tests were conducted by both Minner (unpublished) and Christians (unpublished) that indicated the chlorosis may not be caused by iron deficiency.

In 2006, further work was conducted to determine the cause of summer-induced chlorosis. A nutrient trial was conducted to determine if the chlorosis was a nutritional problem. This trial consisted of varying rates of nitrogen, iron, sulfur, magnesium, manganese, calcium, molybdenum, a soil conditioner, and a plant growth regulator. This experiment indicated that the chlorosis was due to an iron deficiency.

Due to the timing of the deficiency, we hypothesized that environmental conditions may be causing the chlorosis. Other studies have shown that both high and low temperatures can cause iron chlorosis in plants (Clark and Reinhard, 1991; and Wallace and Lunt, 1960). In 2007, field and greenhouse experiments were conducted that applied different root zone temperatures to Kentucky bluegrass turf. A Heatway® snowmelting system and Neslab RTE-111 circulating baths were used to apply temperature treatments. These studies were conducted to see if increased root zone temperature can generate temperature-induced chlorosis.

In 2006 and 2007, a two year study on iron fertilization rates was conducted. The goal of this study was to determine if iron application could correct summer-induced chlorosis. Iron was applied to chlorotic turf after the onset of symptoms and color ratings were taken to assess the efficacy of iron treatments.

In 2007, iron fertilizer was applied before the appearance of chlorosis to Kentucky bluegrass turf that was known to become chlorotic during the summer. This study was performed to see if preventive iron fertilization can be used to stop summer-induced chlorosis from appearing.

In 2007, different iron fertilizers were applied to chlorotic turf to determine what affect chelate formulation had on correcting summer-induced iron chlorosis. Applications were made after the onset of chlorosis. The objective of this study was to determine if the type of iron applied had an effect on recovery of Kentucky bluegrass from summer-induced chlorosis.

THESIS ORGANIZATION

This thesis is divided into five chapters. The first chapter explains background information pertinent to this research and why it was performed. Chapter two is a manuscript on summer-induced chlorosis and how it was effectively controlled. Chapter three is a manuscript on soil temperature studies that were conducted to generate summer-induced chlorosis. Chapter four is a report describing work that was done to evaluate three experimental iron fertilizers. Chapter five is a summary of all the research that was conducted.

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CONTROL OF SUMMER-INDUCED CHLOROSIS ON KENTUCKY BLUEGRASS TURF

David M. DeVetter, Nick E. Christians, and David D. Minner

ABSTRACT

Summer-induced chlorosis is the yellowing of turf from the middle of July to early September in the upper Midwest of the United States. The objectives of this study were to determine the cause of summer induced chlorosis and how to effectively alleviate the symptom. Studies were conducted at the Iowa State University horticulture research station on an area of ‘Unique’ Kentucky bluegrass (*Poa pratensis* L.) turf that annually becomes chlorotic. A nutrient trial showed that summer-induced chlorosis will diminish with the application of iron fertilizers. Higher rates of iron led to better control of chlorosis. Timing of iron application is important and preventive applications are not successful in controlling chlorosis. For turf experiencing summer-induced chlorosis, an application of iron fertilizer at the rate of 0.75 kg Fe/ha should be applied to turf after chlorosis has fully developed.

INTRODUCTION

Chlorosis is a yellowing of plant tissue that is normally green. Chlorosis of turf has always been common and can be due to many factors. Deficiencies of nitrogen, manganese, and iron are some common nutritional causes of chlorosis. Biotic stresses such as disease and abiotic stresses such as low light can also cause chlorosis.

In the last ten years, we have observed a new phenomenon. We are seeing summer-induced chlorosis which is a yellowing of turf in the summer, but not in the spring and fall.

Summer-induced chlorosis is widespread and has been observed in multiple countries on golf courses, home lawns, and sport fields. While summer-induced chlorosis generally appears on sand based root zones, it has also been seen on finer textured soils.

Having adequate nutrients in the root zone is one of the most important aspects to growing healthy turf (Happ, 1995). Deficiencies and toxicities can lead to quality decline, loss of vigor, and impaired health of grass (Beard, 1973). Iron is the most abundant micronutrient found in surface soils (Fageria et. al., 2002), yet deficiencies are common.

Iron is immobile within plants and during deficiency, chlorosis is first observed on new growth. Chlorophyll concentration is low in iron deficient plants because iron is a cofactor involved in chlorophyll synthesis. Iron also plays a role in respiration and protein synthesis due to the function of ferredoxin and cytochromes.

In the soil solution, iron is present in two valence forms, ferrous iron (Fe^{2+}) and ferric iron (Fe^{3+}). The solubility of both valence states is low, but Fe^{2+} is more soluble. The Fe^{2+} form is oxidized to Fe^{3+} in soils where oxygen is present. Soil pH also plays a role in the solubility of iron. The solubility of iron drops dramatically as pH increases. The Fe^{2+} form is 100 times less soluble for every 1 unit increase in pH. The Fe^{3+} form is 1000 times less soluble for every 1 unit increase in pH. Along with alkaline conditions, calcareous soils are likely to have low iron solubility (Chen and Barak, 1982; Rutland and Bukovac, 1971; and Boxma, 1972). Calcium carbonate ($CaCO_3$) in the soil leads to the formation of bicarbonate (HCO_3^-) which favors the formation of Fe^{3+}.

Iron chlorosis has been observed on many turfgrass species, both cool-season and warm-season (Harivandi, 1987). The primary way to treat iron chlorosis in turf is through fertilization (Minner and Butler, 1982). While iron applications have been shown to increase chlorophyll and color of turfgrass, responses are temporary (Minner and Butler, 1984). Cultivar susceptibility to iron chlorosis is variable in Kentucky bluegrass (Harivandi and Butler, 1980).

Our first objective was to determine what causes summer-induced chlorosis. After seeing a curative response from iron fertilizer, we focused on how to effectively use iron to correct summer-induced chlorosis. Our goals were to determine the best rates and timing of application of iron fertilizer for controlling summer-induced chlorosis.

MATERIALS AND METHODS

A sand pad was constructed at the Iowa State University horticulture research station in 1999. Calcareous sand with a pH of 8.2 was spread to a depth of 20 cm. Physical properties of the sand met recommendations of the United States Golf Association (USGA, 1993) for a sand based putting green. ‘Unique’ Kentucky bluegrass was seeded on the sand pad. The turf received 8 kg N/ha per month during May through October of the first year. Subsequently, N was applied at 32 kg/ha annually. The turf was maintained at a mowing height of 7.62 cm.

Nutrient study

A nutrient study was initiated on the sand pad on 6 August 2006. Rates of seven elements (Fe, N, S, Mg, Mn, Cu, and Mo), an experimental soil conditioner from Grain Processing Corp., and a plan growth regulator (Primo MAXX) were evaluated in relation to the control in a randomized complete block with three replications (Table 1). Data was taken on days 0, 5, 10, and 15 by visually assessing the color of the turf on a scale from 9 to 1 with 9 = best, 6 = acceptable, and 1 = poorest color. Plots were 30 cm by 30 cm maintained at a 7.62 cm mowing height. All treatments except the soil conditioner were applied as liquid applications using a spray bottle. To ensure uniform coverage a total spray volume of 1614 l/ha was used.

Two year iron rate study

A two year iron fertilizer rate experiment was conducted on a different location on the sand pad to determine if chlorosis could be minimized. There were five treatments consisting of an untreated control, 0.084 kg Fe/ha, 0.37 kg Fe/ha, 0.75 kg Fe/ha, and 1.12 kg Fe/ha. All iron added in this experiment was from the product Sprint® 138 from Becker Underwood (Ames, IA) which contains Iron Ethylenediamine (di-o-hydroxyphenylacetic acid) (Fe EDDHA). Applications for this experiment were made on 16 August 2006, to chlorotic turf. Data was taken on days 0, 6, and 11 by visually assessing the color of the turf using the same scale as the previous experiment. The treatments were set up as a randomized complete block design with three replications. Plots were 1.5 m by 1.5 m maintained at a 7.62 cm mowing height. All treatments were mixed for a total spay volume of 1222 l/ha. Applications were made using a carbon dioxide powered backpack sprayer pressurized to 262 kPa. The same study was repeated in 2007 with application of treatments made on July 16, at incipient chlorosis. Color data were collected with the same number system used in 2006 on days 0, 4, 11, 15, 18, 25, 32, 39, 45, and 52. Clippings were collected on days 18, 25, 32, and 39 at a 3.81 cm height and then dried at 67 degrees C.

Preventive iron treatment study

A study to determine if early iron application could prevent the occurrence of summer-induced chlorosis was conducted in 2007. This study consisted of applying 0.91 kg Fe/ha as Fe EDDHA on separate dates in June and July. Treatment days were 8 June, 20 June, 25 June, 29 June, 6 July, 13 July, 20 July, 27 July, and an untreated control. Data was taken by visually assessing the color as in previous studies. Data was collected on 8 June, 20 June, 25 June, 29 June, 6 July, 13 July, 20 July, 27 July, 3 August, 8 August, and 16 August. The experimental design was a randomized complete block design with three replications. Plots were 91 cm by 91 cm maintained at a 7.62 cm mowing height. All treatments were mixed for a total spay volume of 1222 l/ha. Applications were made using a carbon dioxide powered backpack sprayer pressurized to 262 kPa.

Statistical analysis

All data were analyzed using the PROC MIXED procedure of SAS (SAS Institute, 2005). Treatment means were compared by the difference of least square means. Significance was reported at $P > 0.05$.

RESULTS

Nutrient study

The initial study conducted in 2006 to determine the cause of chlorosis indicated that summer-induced chlorosis is caused by an iron deficiency. Iron fertilizers improved color of chlorotic Kentucky bluegrass plots while no other treatments did. On days 5, 10, and 15, the color rating of plots treated with iron was higher than the color rating for any other treatments (Figure 1, Appendix Table 1). This led to further studies on iron fertilizer treatments.

Two year iron rate study

Color ratings of chlorotic Kentucky bluegrass turf improved following application of chelated iron in 2006 (Figure 2, Appendix Table 2). Six days after application of treatments, the plots that received 1.12 kg Fe/ha and 0.75 kg Fe/ha had higher color ratings than control plots. Eleven days after application of treatments, plots receiving 1.12 kg Fe/ha, 0.75 kg

Fe/ha, and 0.37 kg Fe/ha had higher color ratings than control plots and plots treated with 0.084 kg Fe/ha.

The results of the 2007 trial differed from 2006. We did not see differences in color rating until days 32 and 39 days after application (Figure 3, Appendix Table 3) in 2007. Thirty two days after application of treatments, the plots that received 0.37 kg Fe/ha had higher color ratings than the control plots and the plots treated with 1.12 kg Fe/ha. Thirty-nine days after application of treatments, the plots that received 0.084 kg Fe/ ha and 0.37 kg Fe/ha had higher color ratings than the control plots and plots that received 0.75 kg Fe/ha or 1.12 kg Fe/ha. Clipping weight data that was collected in 2007 showed that treatment had no effect on clipping yield (Figure 4, Appendix Table 4).

Preventive iron treatment study

There were color differences among treatments in 2007 observed on 13 July, 20 July, 3 August, 8 August, and 16 August (Figure 5, Appendix Table 5). Plots that were treated on 20 June, 25 June, 29 June, and 13 July had better color than untreated control plots on 13 July. Plots treated on 20 June had better color than plots treated on 20 July and control plots on 20 July. Plots treated on July 27 had lower color ratings than all other treatments on 3 August. Plots treated on 29 June had the best color while plots treated on 27 July had the worst color on 8 August. Plots treated on 13 July had the best color while control plots had the worst color on 16 August.

DISCUSSION

Initially we were uncertain why turf becomes chlorotic from the middle of July into September. The nutrient study in 2006 showed that iron was the only nutrient that increased the color of chlorotic Kentucky bluegrass on the sand pad. There are other studies that have shown that nitrogen fertilization can worsen iron deficiency chlorosis in turf (Ferguson et. al., 1986), but we did not see this in this study.

In the iron rate study, color rating results differed from 2006 and 2007. In 2006 we saw that application of iron to chlorotic turf improved color after 6 days and that by 11 days after application the higher rates of iron led to better turf color. We did not see a color response to fertilizer applications until 32 days after application in 2007. When we did see differences in color for the treatments the higher rates of iron did not cause highest color ratings.

We hypothesize that differences in response over the two years can be partially explained in the different times of iron application. In 2006, the iron was applied to severely chlorotic turf in the middle of August. In 2007, the iron was applied at the onset of chlorosis symptoms in the middle of July. Since iron fertilizer applications will not remain soluble in the soil for very long (Brady and Weil, 2002), the application that was made before severe chlorosis might not have had a long enough efficacy to reduce chlorosis. The color response observed may be due to foliar uptake of the iron with no prolonged benefit from the iron staying available to plants in the soil solution.

Preventive iron application did not work as well as curative applications of iron fertilizer. For those who experience the problem of summer-induced chlorosis, treatments should be made after color decline has occurred.

While studies in the past have shown increases in clippings from iron applications (Sloan et. al., 2005), our data suggests that there was no iron effect on clipping weight. Further studies are needed to determine if timing of iron application leads to a plant growth response.

Our findings are a starting point for further work to investigate summer-induced iron chlorosis. Studies that look at iron availability in the soil could be conducted. In a manner similar to that of Garcia-Mina et. al. (2003), the amount of total iron in solution over time could be investigated. If there are products that keep iron in solution for a prolonged period of time, preventive iron applications may have better success.

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Table 1. Nutrient study treatments and rates applied on 6 Aug. 2006 to chlorotic 'Unique' Kentucky bluegrass at the Iowa State University horticulture research station.

Fertilizer and rate (kg/ha)	
Nitrogen (Urea)	
	24
	49
	73
Iron (Fe EDDHA)	
	1.1
	2.2
	3.4
Sulfur (Ammonium sulfate)	
	1.1
	2.2
	3.4
Magnesium (Magnesium carbonate)	
	2.2
	3.4
Manganese (Manganese chloride)	
	0.6
	1.1
Calcium (Calcium carbonate)	
	2.2
Molybdenum (Ammonium molybdate)	
	0.1
Soil conditioner (Grain Processing Corp. experimental formulation)	
	1955
Plant growth regulator (Promo MAXX)	
	1.9 l/ha

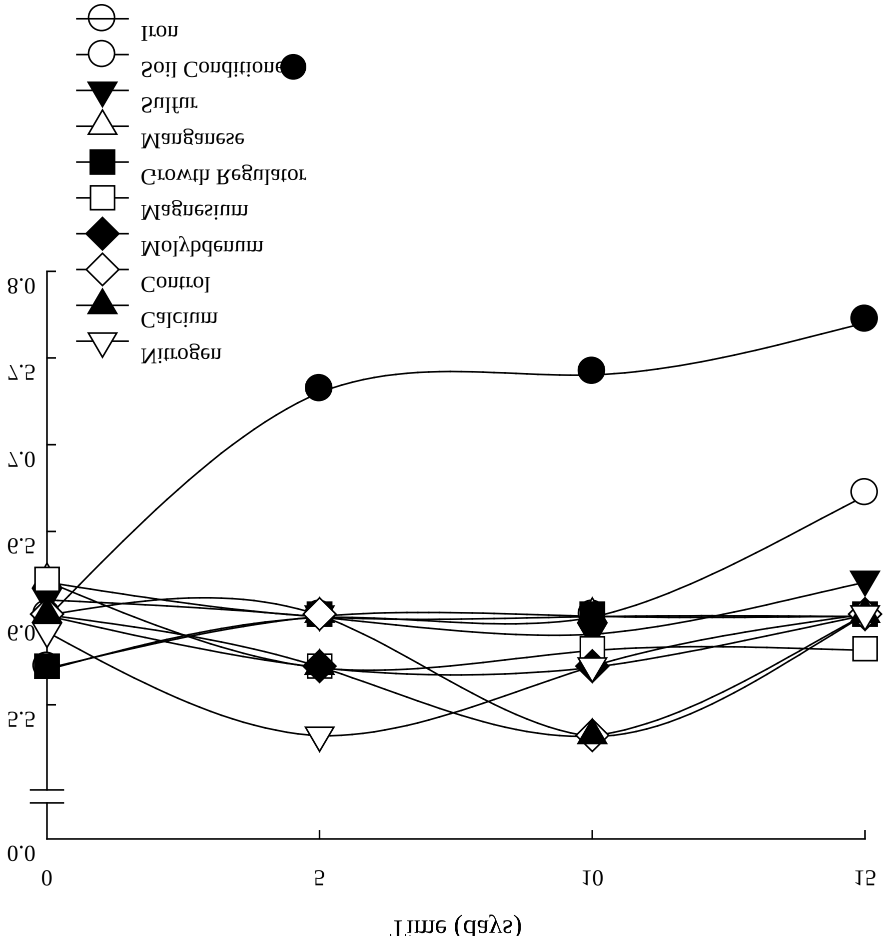

Figure 1. Mean color rating of Kentucky bluegrass plots after fertilization with different nutrients. Data points are the mean of three experimental units. Color was assessed visually on a scale of 9 to 1 with 9 = best, 6 = acceptable, and 1 = poorest color. S.E.D. (standard error of difference) for comparison among treatments = 0.61.

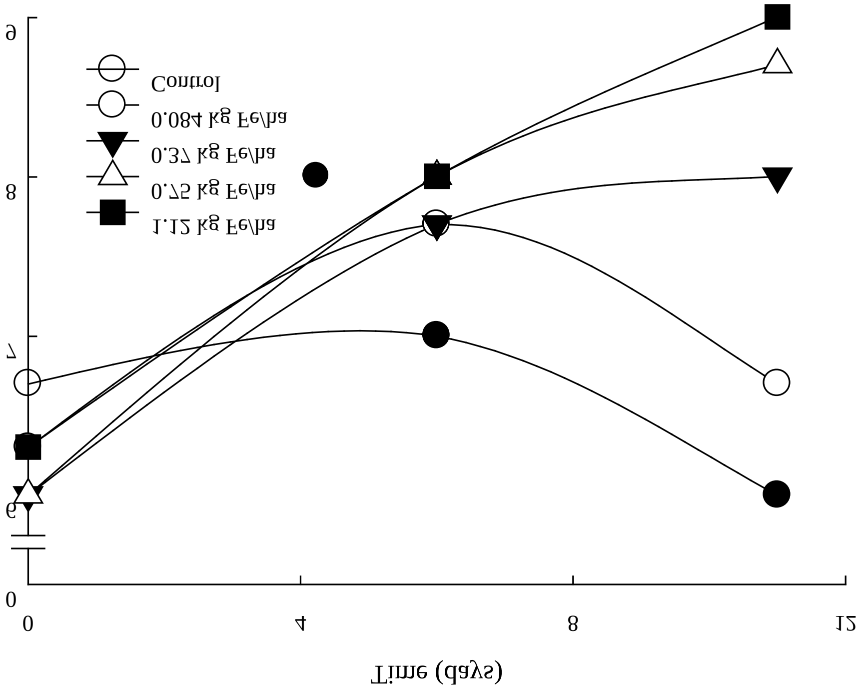

Figure 2. Mean color rating of Kentucky bluegrass plots during an iron fertilizer rate study in 2006. Data points are the mean of three experimental units. Color was assessed visually on a scale of 9 to 1 with 9 = best, 6 = acceptable, and 1 = poorest color. S.E.D. (standard error of difference) for comparison among treatments = 0.32.

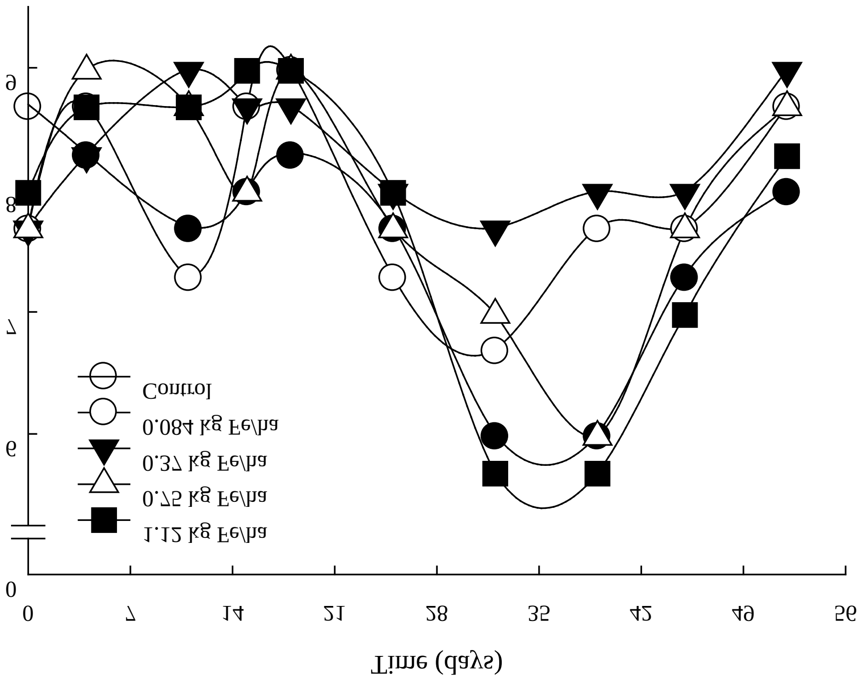

Figure 3. Mean color rating of Kentucky bluegrass plots during an iron fertilizer rate study in 2007. Data points are the mean of three experimental units. Color was assessed visually on a scale of 9 to 1 with 9 = best, 6 = acceptable, and 1 = poorest color. S.E.D. (standard error of difference) for comparison among treatments = 0.69.

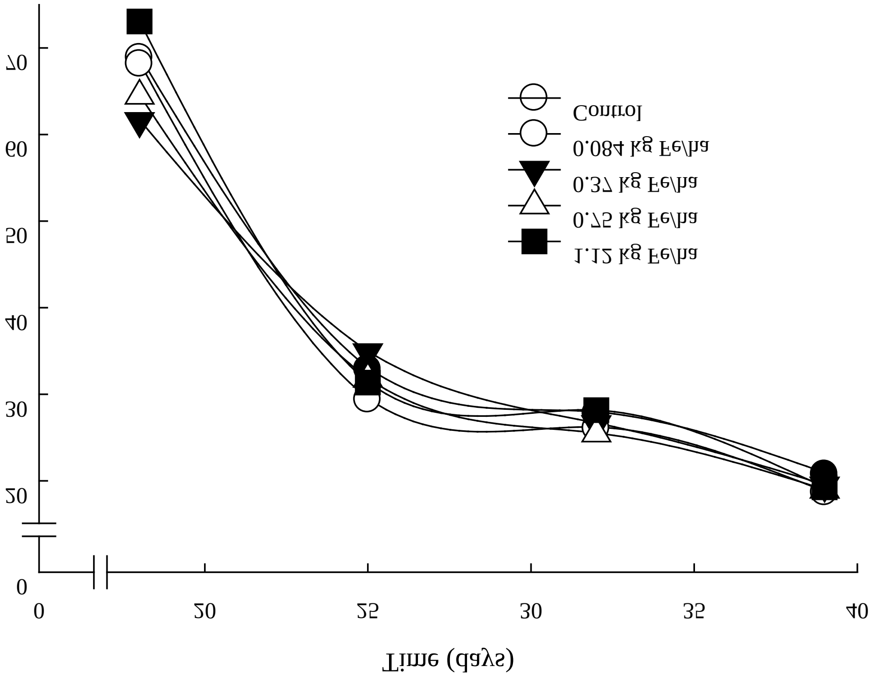

Figure 4. Clipping weight of Kentucky bluegrass plots during an iron fertilizer rate study in 2007. Data points are the mean of three experimental units. Clippings were collected at a 3.8 cm height. Plots were mowed weekly at 3.8 cm. Clippings were collected and dried at 67 degrees C. S.E.D. (standard error of difference) for comparison among treatments = 4.74.

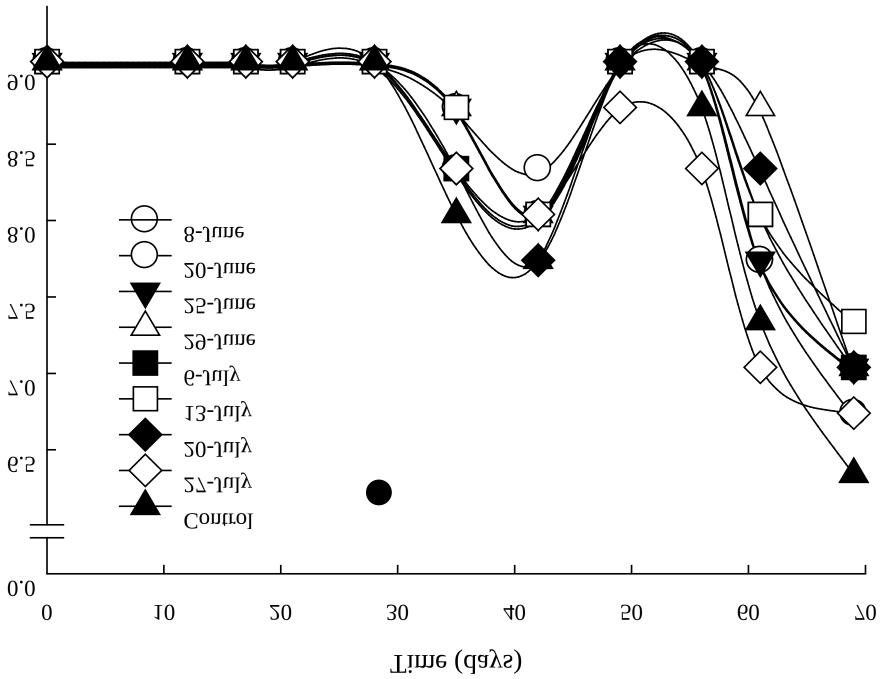

Figure 5. Mean color rating of Kentucky bluegrass plots during an iron fertilization study. Treatments consisted of 1.0 kg Fe/ha being applied to plots on the specified dates. Data points are the mean of three experimental units. Color was assessed visually on a scale of 9 to 1 with 9 = best, 6 = acceptable, and 1 = poorest color. The first day of the study was 8 June 2007. S.E.D. (standard error of difference) for comparison among treatments = 0.31.

INCREASING ROOT ZONE TEMPERATURE CAN SIMULATE SUMMER-INDUCED IRON CHLOROSIS

David M. DeVetter, Nick E. Christians, and David D. Minner

ABSTRACT

Summer-induced iron chlorosis is a yellowing of turf from the middle of July into September. This is a recently observed phenomenon in turf. Due to the timing of chlorosis we hypothesized that increased soil temperatures are playing a roll in causing summer-induced iron chlorosis. Field and greenhouse studies with increased root zone temperature were conducted to see if summer-induced iron chlorosis could be simulated on ‘Unique’ Kentucky bluegrass (*Poa pratensis* L.). Color rating of turf was not reduced by root zone temperature treatments of 18.3, 23.9, and 29.4 degree C in a greenhouse study but chlorophyll was reduced in the 29.4 degree C root zone temperature treatment. In a field study at the Iowa State University horticulture research station, root zone temperature of 34.7 and 39.5 degrees C caused chlorosis of Kentucky bluegrass turf.

INTRODUCTION

Iron is the most abundant micronutrient in surface soils (Fageria et. al., 2002), yet deficiency of iron is common. When a plant is deficient in iron, it becomes chlorotic. Chlorosis is a yellowing of plant tissue that is normally green.

The yellowing symptom of iron deficiency occurs because iron is involved in chlorophyll production in plants. Iron is a cofactor in the pathway of chlorophyll synthesis. When iron is deficient, plants can not produce chlorophyll, and they lose their green color.

Iron in the plant is also important to antioxidant activity, energy transfer, lignin formation, and nitrogen fixation.

Iron is present in the soil in two valence states, ferrous iron (Fe^{2+}) and ferric iron (Fe^{3+}). The Fe^{2+} form is more soluble than Fe^{3+}, but the solubility of both is low. When oxygen is present, Fe^{2+} is oxidized to Fe^{3+}. Soil pH can dramatically change the solubility of iron. As pH increases one unit, Fe^{2+} becomes 100 times less soluble, and Fe^{3+} becomes 1000 times less soluble.

When iron precipitates out of the soil solution, it is unavailable to plants. Because high pH drops the solubility of iron, it also decreases iron availability. Calcareous soils are also prone to have low iron availability due to a high pH and free calcium carbonate ($CaCO_3$). The $CaCO_3$ in the soil leads to the formation of bicarbonate (HCO_3^-) which favors Fe^{3+} formation. Other factors that can lead to iron deficiency are cool soil temperatures, low soil organic matter (S.O.M.) and antagonism from other elements (Harivandi 1986).

Iron chlorosis has been observed on turf for years. Many turfgrass species, both warm-season and cool-season, are affected by iron chlorosis. Research has shown that application of iron fertilizer is the main way to control iron chlorosis and that nitrogen may increase chlorosis (Minner and Butler, 1982). Other studies on Kentucky bluegrass have shown that there are cultivar differences in susceptibility to iron deficiency (Harivandi and Butler, 1980).

Recently iron chlorosis has been appearing for a brief time from the middle of July until September. The chlorosis will go away on its own without iron application. This phenomenon has been observed worldwide and has been seen on golf courses, sports fields, and home lawns. While summer-induced iron chlorosis is commonly observed on turf grown in sand soils, it has been seen on turf grown on finer textured soils.

By looking at what time of the year summer-induced iron chlorosis is observed, we hypothesized that high temperature may be a factor in causing chlorosis. Other studies have shown that temperature can have an impact on iron deficiency chlorosis. Chaney (1988) showed that species vary in their susceptibility chlorosis brought about by cool temperature. Another study showed that cold temperature along with nitrogen induced chlorosis of creeping bentgrass (Ferguson et. al., 1986).

The primary objective of this study was to determine if high root-zone temperature could generate summer-induced iron chlorosis on Kentucky bluegrass. Further objectives were to determine if high root zone temperature caused a decrease in overall quality, growth, and chlorophyll content of Kentucky bluegrass.

MATERIALS AND METHODS

Greenhouse

In 1999, a sand pad was constructed at the Iowa State University horticulture research station. Calcareous sand with a pH of 8.2 was spread to a depth of 20 cm and ‘Unique’ Kentucky bluegrass was planted on the site. The turf received 8 kg N/ha per month during May through October of the first year. Subsequently, N was applied at 32 kg/ha annually. The turf was maintained at a mowing height of 7.62 cm. Plugs of turf were taken from the sand pad, planted into 4.5 inch geranium pots, and then acclimated in a greenhouse until they were subjected to temperature treatments.

A soil temperature study was conducted with treatments of 18.3, 23.9, and 29.4 degrees C. Neslab RTE-111 circulation waterbaths were used to control root zone temperature. The waterbaths circulated water into plastic tubs that each contained four plugs of turf. Treatments were replicated three times so that each waterbath controlled the temperature of each treatment once. The experiment was conducted in a greenhouse under a 400 watt Sun System III greenhouse lamp. Data was collected by visually assessing color and quality of turf on days 0, 2, 4, 7, 9, 11, 14, 16, 18, 21, 23, 25, and 28. Color was assessed visually on a scale of 9 to 1 with 9 = best, 6 = acceptable, and 1 = poorest color. Overall quality based on vigor, uniformity, and plant density was assessed visually on a scale of 9 to 1 with 9 = best, 6 = acceptable, and 1 = poorest color. Clippings were taken weekly on days 7, 14, 21, and 28. Clippings were place in a drying oven at 67 degrees C and dried to uniform weight. Chlorophyll content was measured at the end of 28 days of treatments. Chlorophyll was extracted and measured using formulas presented in Inskeep and Bloom (1985).

Field

A root zone temperature experiment was conducted in field plots using a Heatway® snowmelting system that was previously installed at the Iowa State University horticulture research station in 1996. The system consists of a hot water boiler that is connected to tubing that runs underneath turf plots. A 50:50 mixture of water and polyethylene glycol runs through the system. Tubing was place at a 30 cm depth and spaced 20 cm apart throughout the plots. The soil above the heating system was calcareous sand and met the specifications of a United States Golf Association putting green (USGA, 1993). ‘Unique’ Kentucky bluegrass was established on the site. The system allowed three temperature treatments to be replicated twice. Plots were 3 meters by 4.6 meters. In the corner of each plot a subplot that was 91 cm by 91 cm was set up. The soil temperatures for the three treatments averaged

23.5, 34.7, 39.5 degrees C at a depth of 7.62 cm. Temperature treatments were maintained for 15 days. On day 0 of the study, subplots were fertilized with iron at a rate of 1.12 kg Fe/ha. Color was assessed visually on a scale of 9 to 1 with 9 = best, 6 = acceptable, and 1 = poorest color. Data was taken on days 1, 5, 11, 12, 20, 24, and 31. Chlorophyll content of leaf tissue was taken on day five. Turf clippings were taken randomly throughout the plots and chlorophyll was extracted according to Inskeep and Bloom (1985).

Statistical analysis

All data were analyzed using the PROC MIXED procedure of SAS (SAS Institute, 2005). Treatment means were compared by the difference of least square means. Significance was reported at $P > 0.05$.

RESULTS

Greenhouse

Soil temperature had no effect on the color rating of Kentucky bluegrass plugs grown in waterbaths. Over 28 days of increased soil temperature the treatments had the same color rating (Figure 1, Appendix Table 6). The minimum and maximum color rating for turf plugs in the experiment never varied by more than one unit.

Soil temperature had limited effect on overall quality of Kentucky bluegrass plugs grown in waterbaths. Over 28 days of increased soil temperature, only day 28 showed treatment differences (Figure 2, Appendix Table 7). After 28 days, plants grown at 29.4 degrees C had better overall quality than plants grown at 18.3 and 23.9 degrees C.

Increased soil temperature had no effect on biomass production of Kentucky bluegrass plugs. Over the 28 day treatment period, there was never a difference in clipping weight for the treatments (Figure 3, Appendix Table 8).

Chlorophyll concentration of leaf tissue measured 28 days into the experiment showed that high root zone temperatures led to less chlorophyll in the plant. The 18.3 degree C and 23.9 degree C treatments had higher chlorophyll concentrations than the 29.4 degree C treated plants (Table 1).

Field

Soil temperature treatments affected turf color in field plots. On days 5, 11, and 12 color of the 23.5 degree treatment was highest, followed by the 34.7 degree treatment, with the 39.5 degree treatment having the lowest color rating. On days 20 and 24, the 23.5 degree treatment had the highest color, followed by the 39.5 degree treatment, with the 34.7 degree treatment having the lowest color rating (Figure 4, Appendix Table 9). Color of subplots that had iron fertilizer applied all had a color rating of 9 through out the study.

Chlorophyll contents of leaves sampled from the Heatway showed that the 23.5 degree treatment had 5.13 mg chl/g dry tissue, the 34.7 degree treatment had 4.35 mg chl/g dry tissue, and the 39.5 degree temperature treatment had 2.83 mg chl/g dry tissue. Due to large variation within treatments, these means are not significantly different.

DISCUSSION

Increased root zone temperature caused a decrease in color of Kentucky bluegrass turf. In the field experiment where temperatures were raised above 30 degrees C, we saw that color rating dropped. In the subplots located on these plots where iron was applied, we did not see color decline. This indicates that we were generating an iron deficiency with heat. Increased root zone temperature of Kentucky bluegrass grown in a greenhouse did not cause a decrease in color. The soil temperature for the greenhouse experiment was not high enough to cause chlorosis.

In both studies there was a decrease in tissue chlorophyll concentration in plants that were grown at high root zone temperatures. This measurement is showing that while there was no color impairment of turf in the greenhouse, chlorophyll production is being affected.

Future studies should be conducted to determine what role temperature plays in causing summer-induced iron chlorosis. Other trials could be conducted using higher root zone temperatures to determine if our greenhouse trials simply did not increase the soil temperature high enough. Taking root mass could be beneficial in understanding the temperature effect as well. Other research could be done to determine what effect temperature has on the plants mechanisms to overcome low iron solubility. Studies have looked at siderophore excretion under iron stress (Ma et. al., 2003; Ma and Nomoto, 1996). Looking at siderophore stability under high temperatures might help in understanding why high temperatures cause summer-induced iron chlorosis.

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Table 1. Chlorophyll content of Kentucky bluegrass plugs during greenhouse heat treatments. Values are the means of three experimental units[†].

Treatment	Chlorophyll content
Temperature (°C)	mg chl/g dry tissue
18.3	5.31a[‡]
23.9	4.86a
29.4	4.06b

[†] Clippings were harvested 28 into temperature treatments.

[‡] Means within columns followed by the same letter are not significantly different at $P \leq 0.05$.

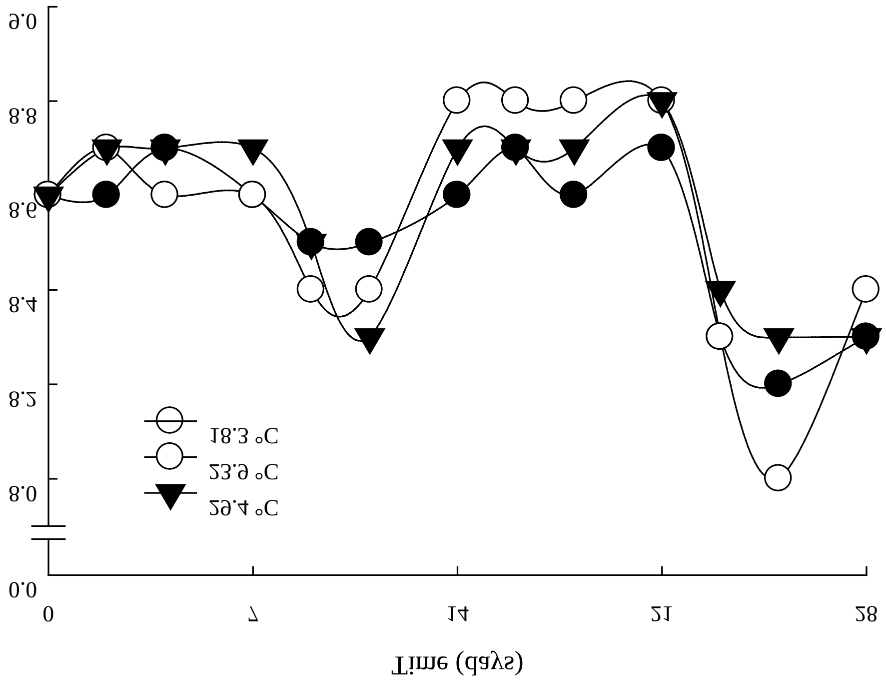

Figure 1. Mean color rating of Kentucky bluegrass plugs during root zone temperature treatments. Data points are the mean of three experimental units. Color was assessed visually on a scale of 9 to 1 with 9 = best, 6 = acceptable, and 1 = poorest color. S.E.D. (standard error of difference) for comparison among treatments = 0.22.

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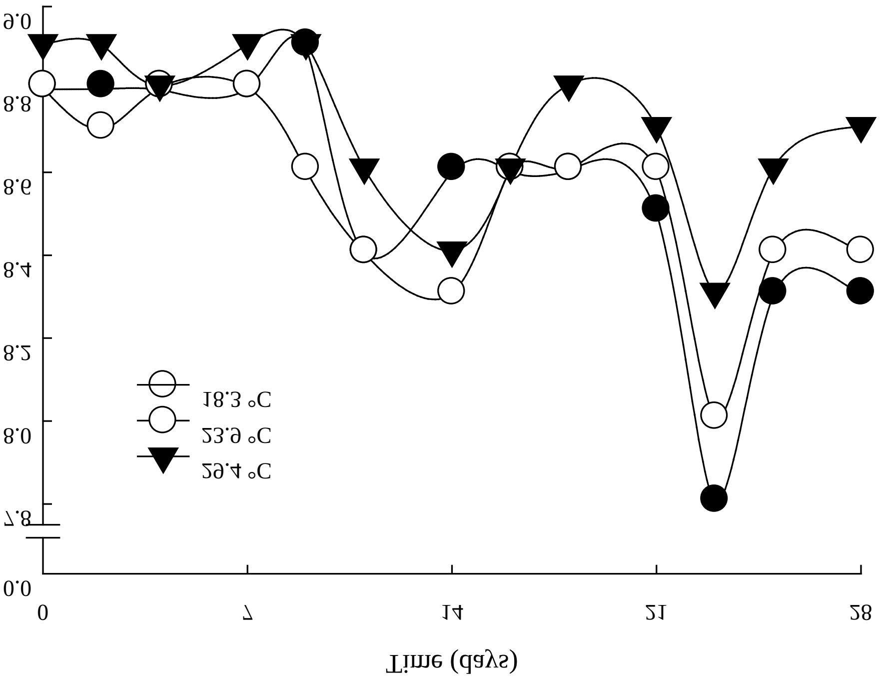

Figure 2. Mean quality of Kentucky bluegrass plugs during root zone temperature treatments. Data points are the mean of three experimental units. Overall quality based on vigor, uniformity, and plant density was assessed visually on a scale of 9 to 1 with 9 = best, 6 = acceptable, and 1 = poorest quality. S.E.D. (standard error of difference) for comparison among treatments = 0.20.

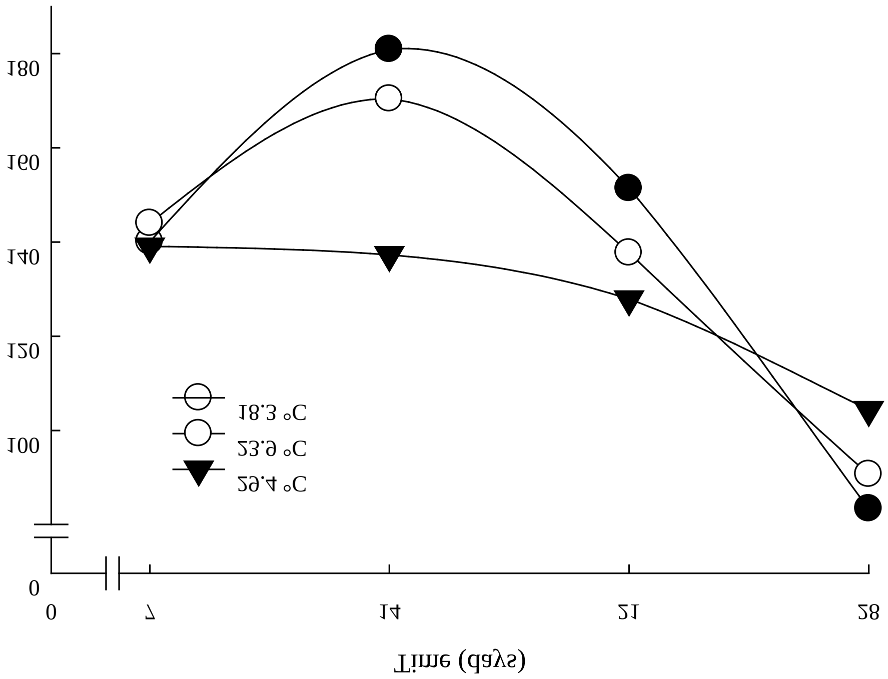

Figure 3. Mean clipping weight of Kentucky bluegrass plugs. Clippings were harvested weekly at 7.62 cm. Data points are the mean of three experimental units. S.E.D. (standard error of difference) for comparison among treatments = 24.20.

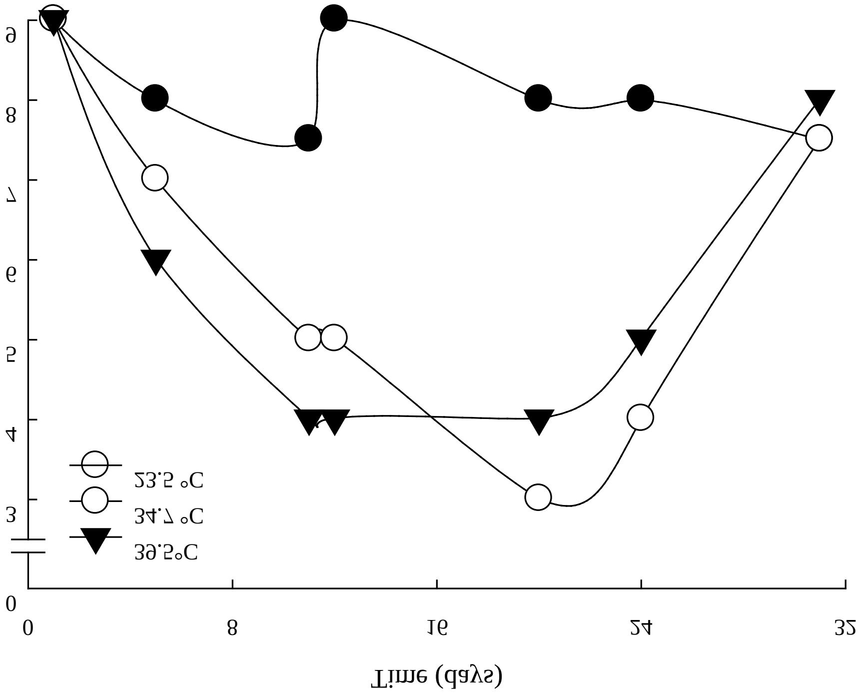

Figure 4. Mean color rating of Kentucky bluegrass field plots during soil temperature treatments. Data points are the mean of two experimental units. Color was assessed visually on a scale of 9 to 1 with 9 = best, 6 = acceptable, and 1 = poorest color. S.E.D. (standard error of difference) for comparison among treatments = 0.27.

STONG CHELATING AGENTS INCREASE COLOR OF CHLOROTIC KENTUCKY BLUEGRASS TURF

David M. DeVetter, Nick E. Christians

ABSTRACT

Some iron fertilizers work better than others at correcting iron chlorosis depending on soil conditions. There are different chelates that keep iron in the soil solution better than others. If an iron fertilizer application is made and the iron becomes insoluble, deficiency will continue. In this study, we tested three experimental chelate formulations and FeRROMEC AC to an untreated control. The objective was to determine which fertilizer was best at controlling iron chlorosis on Kentucky bluegrass (*Poa pratensis* L.) turf. We found that BU EXP 1330C caused a recovery from chlorosis from 4 days after application through 10 days after application. FeRROMEC AC led to a rapid color recovery on turf, but was not long lasting. BU EXP 1330E had moderate color improvement that lasted from day four until day seven. BU EXP 1330D did not reduce chlorosis.

INTRODUCTION

Having adequate nutrients in the root zone is one of the most important aspects to growing healthy turf (Happ, 1995). Deficiencies and toxicities can lead to quality decline, loss of vigor, and impaired health of grass (Beard, 1973). Iron is the most abundant micronutrient found in surface soils (Fageria et. al., 2002), yet deficiencies are common. A yellowing of plant tissue, or chlorosis, occurs when iron is deficient.

Iron is immobile within plants and during deficiency, chlorosis is first observed on new growth. Chlorophyll concentration is low in iron deficient plants because iron is a cofactor involved in chlorophyll synthesis. Iron also plays a role in respiration and protein synthesis due to the function of ferredoxin and cytochromes.

In the soil solution, iron is present in two valence forms, ferrous iron (Fe^{2+}) and ferric iron (Fe^{3+}). The solubility of both valence states is low, but Fe^{2+} is more soluble. The Fe^{2+} form is oxidized to Fe^{3+} in soils where oxygen is present. Soil pH also plays a role in the solubility of iron. The solubility of iron drops dramatically as pH increases. The Fe^{2+} form is 100 times less soluble for every 1 unit increase in pH. The Fe^{3+} form is 1000 times less soluble for every 1 unit increase in pH. Along with alkaline conditions, calcareous soils are likely to have low iron solubility (Chen and Barak, 1982; Rutland and Bukova, 1971; and Boxma, 1972). Calcium carbonate ($CaCO_3$) in the soil leads to the formation of bicarbonate (HCO_3^-) which favors the formation of Fe^{3+}.

Iron chlorosis has been observed on many turfgrass species, both cool-season and warm-season (Harivandi, 1987). The primary way to treat iron chlorosis in turf is through fertilization (Minner and Butler, 1982). While iron applications have been shown to increase chlorophyll and color of turfgrass, responses are temporary (Minner and Butler, 1984). Cultivar susceptibility to iron chlorosis is variable in Kentucky bluegrass (Harivandi and Butler, 1980).

Iron fertilization of turf can have poor results if the iron precipitates out of solution. There are fertilizers that contain chelated iron that keep iron in solution longer. Different chelates have been shown to keep iron in solution better than others (Garcia-Mina et. al., 2003). In this study we will compare three experimental chelates to an industry standard and an untreated control. The objective is to see which chelate formulations are the best at controlling iron chlorosis.

MATERIALS AND METHODS

A sand pad was constructed at the Iowa State University horticulture research station in 1999. Calcareous sand with a pH of 8.2 was spread to a depth of 20 cm. Physical properties of the sand meet recommendations of the United States Golf Association (USGA, 1993) for a sand based putting green. 'Unique' Kentucky bluegrass was seeded on the sand pad. The turf received 8 kg N/ha per month during May through October of the first year. Subsequently, N was applied at 32 kg/ha annually. The turf was maintained at a mowing height of 7.62 cm.

Treatments were applied to chlorotic Kentucky bluegrass on 9 August 2007. Treatments consisted of an untreated control, and four iron fertilizers (FeRROMEC AC, BU EXP 1330C, BU EXP 1330D, and BU EXP 1330E). All products were applied at a rate of 1.2 kg Fe/ha. Plots were 1.5 m by 1.5 m. The experimental design was a randomized complete block design (RCBD) with three blocks.

Data was collected by visually assessing color of turf 0, 1, 4, 7, 10, 14, 21, and 28 days after treatment application. Color was assessed on a scale of 9 to 1 with 9 = best, 6 = acceptable, and 1 = poorest color. Color was also measured using a Spectrum Technologies Inc., TCM 500 "NDVI" Turf Color Meter. Normalized Difference Vegetation Index (NDVI) readings were taken 0, 1, 4, 7, 14, 21, and 28 days after application of treatments. Chlorophyll content of leaf tissue was taken 0, 7, and 21 days after application of treatments. Turf clippings were taken randomly throughout the plots and chlorophyll was extracted according to Inskeep and Bloom (1985).

Data were analyzed using the PROC MIXED procedure of SAS (SAS Institute, 2005). Analysis treated the experiment as a split-plot design with time being the whole unit and treatments were the sub units. Treatment means were compared by the difference of least square means. Significance was reported at $P > 0.05$.

RESULTS

Four days after application, plots treated with FeRROMEC AC, BU EXP 1330C, and BU EXP 1330E had higher color ratings than control plots (Figure 1, Appendix Table 10). Seven days after application, plots treated with BU EXP 1330C, BU EXP 1330E, and FeRROMEC AC had higher color ratings than control plots. Ten days after application, only plots treated with BU EXP 1330C had higher color ratings than control plots. Color difference was also observed with the NDVI measurement (Figure 2, Appendix Table 11). Seven days after application, plots treated with BU EXP 1330C had higher NDVI values than control plots and plots treated with BU EXP 1330D.

Seven days after application of treatments, plots treated with FeRROMEC AC had higher chlorophyll concentration than control plots (Figure 3, Appendix Table 12). No other differences in chlorophyll concentration were observed.

DISCUSSION

The most effective fertilizer at treating iron chlorosis was BU EXP 1330C. The fertilizer led to increase in color that lasted longer than other fertilizers. It was expected that formulation with the strongest chelating agents would increase color for longer periods of time.

The other fertilizer that had a large and rapid color response was FeRROMEC AC. This product led to an increase in color of chlorotic turf by day four, but was gone by day seven. Application of this product also had an increase in chlorophyll concentration of plant tissue at day seven of the experiment.

The remaining products (BU EXP 1330D and BU EXP 1330E) did not green up chlorotic turfgrass very effectively. BU EXP 1330E did show a moderate color response but did not last. BU EXP 1330D never increased the color of chlorotic Kentucky bluegrass.

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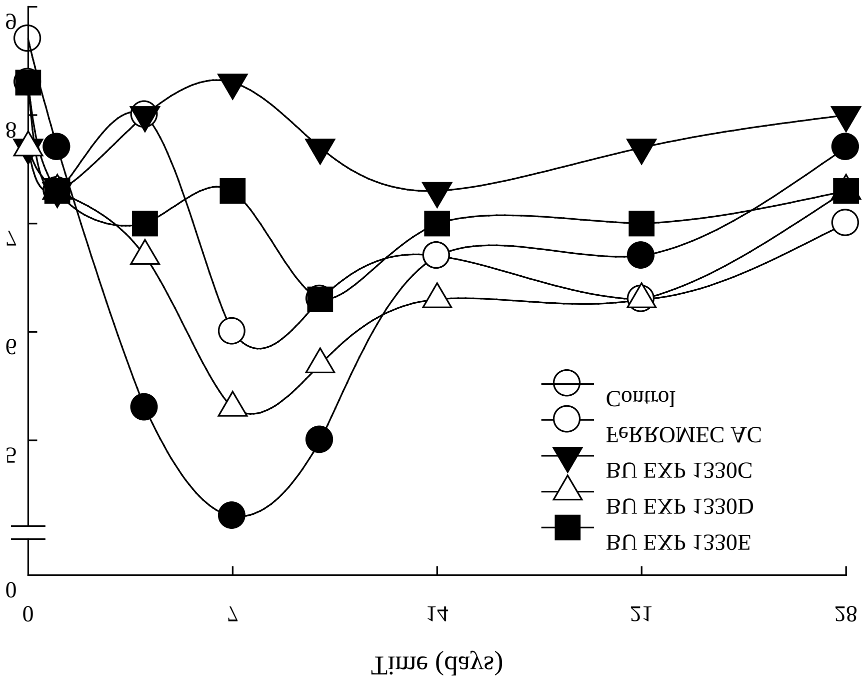

Figure 1. Mean color rating of Kentucky bluegrass plots after fertilization with different iron chelate formulations. Data points are the mean of three experimental units. Color was assessed visually on a scale of 9 to 1 with 9 = best, 6 = acceptable, and 1 = poorest color. S.E.D. (standard error of difference) for comparison among treatments = 0.70.

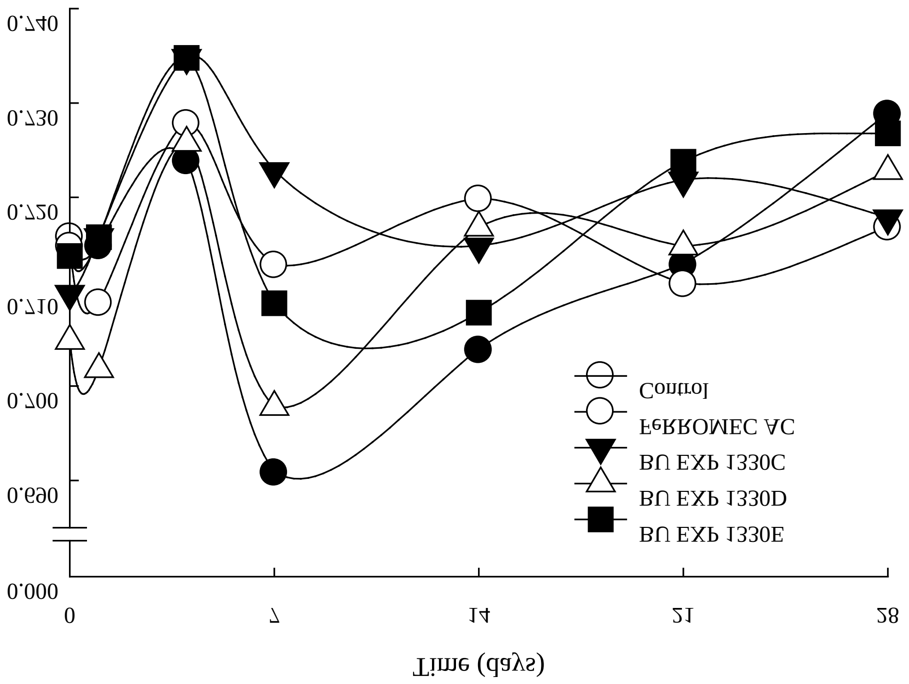

Figure 2. Mean NDVI score of Kentucky bluegrass plots after fertilization with different iron chelate formulations. Data points are the mean of three experimental units. NDVI (Normalized Difference Vegetative Index) measurements were taken with a Spectrum Technologies Inc., TCM 500 Turf Color Meter. S.E.D. (standard error of difference) for comparison among treatments = 0.010.

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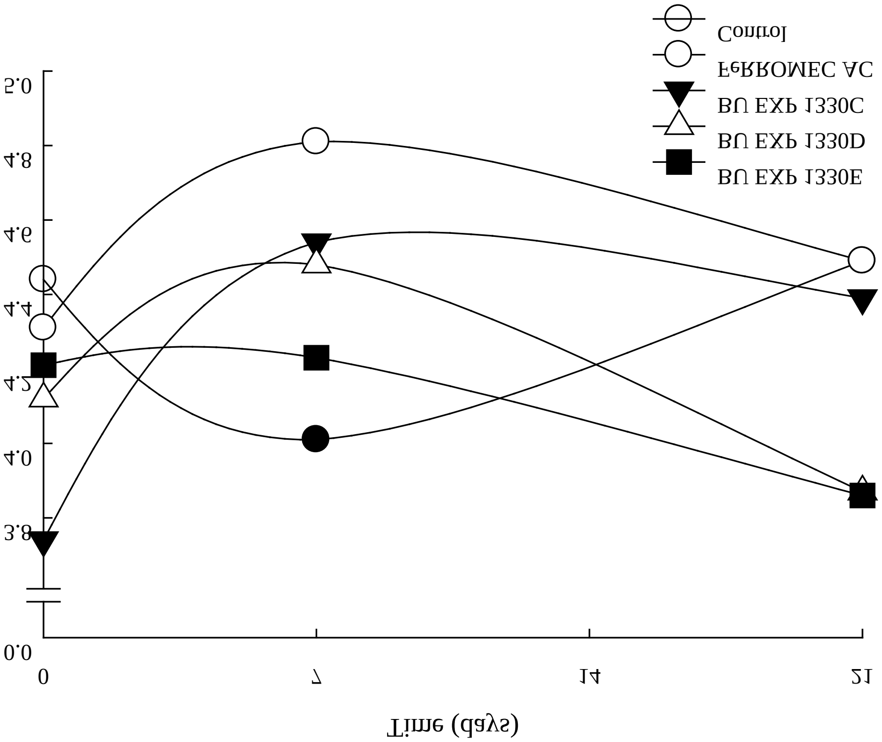

Figure 3. Mean chlorophyll content of Kentucky bluegrass plots after fertilization with different iron chelate formulations. Data points are the mean of three experimental units. S.E.D. (standard error of difference) for comparison among treatments = 0.29.

GENERAL CONCLUSION

Chlorosis of turf has always been common for grass grown on high pH soils. In the last ten years, however, we have observed a new phenomenon. We are seeing summer-induced chlorosis which is a yellowing of turf in the summer, but not in the spring and fall. Summer-induced chlorosis is widespread and has been observed in multiple countries on golf courses, home lawns, and sport fields. While summer-induced chlorosis generally appears on sand based root zones, it has also been seen on finer textured soils.

Iron fertilization

Studies have shown that application of iron will control iron deficiency chlorosis (Minner and Butler, 1984). Our studies found that application of iron fertilizer was an effective control of summer-induced iron chlorosis on Kentucky bluegrass (*Poa pratensis* L.) turf. Higher rates of iron fertilizer led to better color recovery of chlorotic turf. Timing of application is important for getting good control of summer-induced iron chlorosis. Application of iron should be made after chlorosis has fully developed. If iron is applied at first site of chlorosis, control may control may not last long enough to prevent severe chlorosis. Preventive applications of iron fertilizers were not effective at controlling summer-induced iron chlorosis.

Increased root zone temperature

Other studies have shown that low temperatures can cause iron deficiency chlorosis to appear on turfgrass (Ferguson et. al., 1986). Our studies were conducted to see if high root zone temperatures could cause summer-induced iron chlorosis to appear on Kentucky bluegrass turf. We found that if root zone temperatures were increased above 34 degrees C, iron chlorosis would occur while root zone temperatures lower than 30 degrees C did not generate chlorosis.

Fertilizer formulation

We found that BU EXP 1330C was effective at controlling summer-induced iron chlorosis when applied to chlorotic Kentucky bluegrass. FeRROMEC AC caused a greening response on the turf, but was gone by day seven of the experiment. BU EXP 1330E caused a moderate greening of chlorotic turf that lasted through day seven of the experiment. BU EXP 1330E was not effective at controlling summer-induced iron chlorosis.

Future work

To further understand summer-induced iron chlorosis, work could be conducted to discover what is happening in the soil that causes iron to become unavailable from mid July into September. Other studies could focus on how long various chelates keep iron in solution during this time period. Lucena (2003) found that only the most stable chelates can keep iron in solution and get it to the roots. If some chelates keep iron in solution long enough, preventive control of summer-induced iron chlorosis may be possible. Finally, studies could be conducted to see if the plants natural pathways to acquire iron are impeded by high soil temperatures. Phytosiderophores have been shown to increase iron uptake (Ma and Nomoto, 1996), but knowing the conditions that limit their activity in the soil would be beneficial.

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APPENDIX

Table 1. Color rating of Kentucky bluegrass turf after nutrient fertilization in 2006. Values are the means of nine experimental units for Fe, N, and S; six experimental units for Mg, and Mn; and three experimental units for the control, Ca, Mo, soil conditioner, and growth regulator[†].

	Days after application			
Treatment	0	5	10	15
Iron	6.0a[‡]	7.3a	7.4a	7.7a
Soil Conditioner	5.7a	6.0b	6.0b	6.7b
Sulfur	6.1a	6.0b	5.9b	6.2b
Manganese	6.2a	6.0b	6.0b	6.0b
Growth Regulator	5.7a	6.0b	6.0b	6.0b
Magnesium	6.2a	5.7b	5.8b	5.8b
Molybdenum	6.0a	5.7b	5.7b	6.0b
Control	6.0a	6.0b	5.3b	6.0b
Calcium	6.0a	5.7b	5.3b	6.0b
Nitrogen	5.9a	5.3b	5.7b	6.0b

[†] Color rating was assessed visually on a scale of 9 to 1 with 9 = best, 6 = acceptable, and 1 = poorest color.

[‡] Means within columns followed by the same letter are not significantly different at $P \leq 0.05$.

Table 2. Color rating of Kentucky bluegrass turf after iron fertilization in 2006. Values are the means of three experimental units[†].

Treatment	Days after application		
kg Fe/ha	0	6	11
Control	6.7a[‡]	7.0b	6.0c
0.084	6.3a	7.7ab	6.7c
0.37	6.0a	7.7ab	8.0b
0.75	6.0a	8.0a	8.7ab
1.12	6.3a	8.0a	9.0a

[†] Color rating was assessed visually on a scale of 9 to 1 with 9 = best, 6 = acceptable, and 1 = poorest color.

[‡] Means within columns followed by the same letter are not significantly different at $P \leq 0.05$.

Table 3. Color rating of Kentucky bluegrass turf after iron fertilization in 2007. Values are the means of three experimental units[†].

Treatment	Days after application									
kg Fe/ha	0	4	11	15	18	25	32	39	45	52
Control	8.7a[‡]	8.3a	7.7a	8.0a	8.3a	7.7a	6.0b	6.0b	7.3a	8.0a
0.084	7.7a	8.7a	7.3a	8.7a	9.0a	7.3a	6.7ab	7.7a	7.7a	8.7a
0.37	7.7a	8.3a	9.0a	8.7a	8.7a	8.0a	7.7a	8.0a	8.0a	9.0a
0.75	7.7a	9.0a	8.7a	8.0a	9.0a	7.7a	7.0ab	6.0b	7.7a	8.7a
1.12	8.0a	8.7a	8.7a	9.0a	9.0a	8.0a	5.7b	5.7b	7.0a	8.3a

[†] Color rating was assessed visually on a scale of 9 to 1 with 9 = best, 6 = acceptable, and 1 = poorest color.

[‡] Means within columns followed by the same letter are not significantly different at $P \leq 0.05$.

Table 4. Clipping weight of Kentucky bluegrass turf after iron fertilization in 2007. Values are the means of three experimental units.

Treatment	Days after application			
kg Fe/ha	18	25	32	39
Control	69.1a[†]	33.1a	28.0a	21.0a
0.084	68.4a	29.6a	26.3a	18.9a
0.37	61.8a	35.1a	26.8a	19.7a
0.75	64.7a	32.0a	25.7a	19.2a
1.12	73.3a	31.6a	28.4a	19.5a

[†] Means within columns followed by the same letter are not significantly different at $P \leq 0.05$.

Table 5. Color rating of Kentucky bluegrass turf after iron fertilization in 2007. Values are the means of three experimental units[†].

Treatment	Date of color rating									
Date	8-Jun	20-Jun	25-Jun	29-Jun	6-Jul	13-Jul	20-Jul	27-Jul	3-Aug	8-Aug	16-Aug
8-Jun	9.0a[‡]	9.0a	9.0a	9.0a	9.0a	8.3ab	8.0ab	9.0a	9.0a	7.7cd	7.0ab
20-Jun	9.0a	9.0a	9.0a	9.0a	9.0a	8.7a	8.3a	9.0a	9.0a	7.7cd	6.7bc
25-Jun	9.0a	9.0a	9.0a	9.0a	9.0a	8.7a	8.0ab	9.0a	9.0a	7.7cd	7.0ab
29-Jun	9.0a	9.0a	9.0a	9.0a	9.0a	8.7a	8.0ab	9.0a	9.0a	8.7a	7.0ab
6-Jul	9.0a	9.0a	9.0a	9.0a	9.0a	8.3ab	8.0ab	9.0a	9.0a	8.0bc	7.0ab
13-Jul	9.0a	9.0a	9.0a	9.0a	9.0a	8.7a	8.0ab	9.0a	9.0a	8.0bc	7.3a
20-Jul	9.0a	9.0a	9.0a	9.0a	9.0a	8.3ab	7.7b	9.0a	9.0a	8.3ab	7.0ab
27-Jul	9.0a	9.0a	9.0a	9.0a	9.0a	8.3ab	8.0ab	8.7a	8.3b	7.0e	6.7bc
Control	9.0a	9.0a	9.0a	9.0a	9.0a	8.0b	7.7b	9.0a	8.7a	7.3de	6.3c

[†] Color rating was assessed visually on a scale of 9 to 1 with 9 = best, 6 = acceptable, and 1 = poorest color.

[‡] Means within columns followed by the same letter are not significantly different at $P \leq 0.05$.

Table 6. Color rating of Kentucky bluegrass plugs during greenhouse heat treatments. Values are the means of three experimental units[†].

Treatment	Days of treatment											
Temperature	0	2	4	7	9	11	14	16	18	21	23	25	28
18.3 °C	8.6a[‡]	8.6a	8.7a	8.6a	8.5a	8.5a	8.6a	8.7a	8.6a	8.7a	8.3a	8.2a	8.3a
23.9 °C	8.6a	8.7a	8.6a	8.6a	8.4a	8.4a	8.8a	8.8a	8.8a	8.8a	8.3a	8.0a	8.4a
29.4 °C	8.6a	8.7a	8.7a	8.7a	8.5a	8.3a	8.7a	8.7a	8.7a	8.8a	8.4a	8.3a	8.3a

[†] Color rating was assessed visually on a scale of 9 to 1 with 9 = best, 6 = acceptable, and 1 = poorest color.

[‡] Means within columns followed by the same letter are not significantly different at $P \leq 0.05$.

Table 7. Quality rating of Kentucky bluegrass plugs during greenhouse heat treatments. Values are the means of three experimental units[†].

Treatment	Days of treatment											
Temperature	0	2	4	7	9	11	14	16	18	21	23	25	28
18.3 °C	8.8a[‡]	8.8a	8.8a	8.8a	8.9a	8.4a	8.6a	8.6a	8.6a	8.5a	7.8a	8.3a	8.3a
23.9 °C	8.8a	8.7a	8.8a	8.8a	8.6a	8.4a	8.3a	8.6a	8.6a	8.6a	8.0ab	8.4a	8.4ab
29.4 °C	8.9a	8.9a	8.8a	8.9a	8.9a	8.6a	8.4a	8.6a	8.8a	8.7a	8.3b	8.6a	8.7b

[†] Overall quality based on vigor, uniformity, and plant density was assessed visually on a scale of 9 to 1 with 9 = best, 6 = acceptable, and 1 = poorest quality.

[‡] Means within columns followed by the same letter are not significantly different at $P \leq 0.05$.

Table 8. Clipping weight of Kentucky bluegrass plugs during greenhouse heat treatments. Values are the means of three experimental units[†].

Treatment	Days subjected to treatment			
Temperature	7	14	21	28
18.3 °C	140.1a[‡]	180.9a	151.4a	83.4a
23.9 °C	144.0a	170.4a	137.7a	90.7a
29.4 °C	139.1a	137.3a	127.9a	104.4a

[†] Clippings were harvested weekly at a 7.62 cm height.

[‡] Means within columns followed by the same letter are not significantly different at $P \leq 0.05$.

Table 9. Color rating of Kentucky bluegrass plots during field heat treatments. Values are the means of two experimental units[†].

Treatment	Days of temperature treatment						
Temperature	1	5	11	12	20	24	31
23.5 °C	9.0a[‡]	8.0a	7.5a	9.0a	8.0a	8.0a	7.5a
34.7 °C	9.0a	7.0b	5.0b	5.0b	3.0b	4.0b	7.5a
39.5 °C	9.0a	6.0c	4.0c	4.0c	4.0c	5.0c	8.0a

[†] Color rating was assessed visually on a scale of 9 to 1 with 9 = best, 6 = acceptable, and 1 = poorest color.

[‡] Means within columns followed by the same letter are not significantly different at $P \leq 0.05$.

Table 10. Color rating of Kentucky bluegrass turf after iron fertilization in 2007. Values are the means of three experimental units[†].

Treatment	Days after application							
Product	0	1	4	7	10	14	21	28
Control	8.7a[‡]	7.7a	5.3b	4.3d	5.0b	6.7a	6.7a	7.7a
FeRROMEC AC	8.3a	7.3a	8.0a	6.0bc	6.3ab	6.7a	6.3a	7.0a
BU EXP 1330C	7.7a	7.3a	8.0a	8.3a	7.7a	7.3a	7.7a	8.0a
BU EXP 1330D	7.7a	7.3a	6.7ab	5.3cd	5.7b	6.3a	6.3a	7.3a
BU EXP 1330E	8.3a	7.3a	7.0a	7.3ab	6.3ab	7.0a	7.0a	7.3a

[†] Color rating was assessed visually on a scale of 9 to 1 with 9 = best, 6 = acceptable, and 1 = poorest color.

[‡] Means within columns followed by the same letter are not significantly different at $P \leq 0.05$.

Table 11. NDVI of Kentucky bluegrass turf after iron fertilization in 2007. Values are the means of three experimental units[†].

Treatment	Days after application						
Product	0	1	4	7	14	21	28
Control	0.716a[‡]	0.715a	0.724a	0.691c	0.704a	0.713a	0.729a
FeRROMEC AC	0.715a	0.709a	0.728a	0.713ab	0.720a	0.711a	0.717a
BU EXP 1330C	0.710a	0.716a	0.735a	0.723a	0.715a	0.722a	0.718a
BU EXP 1330D	0.705a	0.702a	0.726a	0.698bc	0.717a	0.715a	0.723a
BU EXP 1330E	0.714a	0.716a	0.735a	0.709abc	0.708a	0.724a	0.727a

[†] NDVI was measured with a Spectrum Technologies Inc., TCM 500 Turf Color Meter.

[‡] Means within columns followed by the same letter are not significantly different at $P \leq 0.05$.

Table 12. Chlorophyll content of Kentucky bluegrass turf after iron fertilization in 2007. Values are the means of three experimental units[†].

Treatment	Days after application		
Product	0	7	21
Control	4.44a[‡]	4.01b	4.49a
FeRROMEC AC	4.31ab	4.81a	4.49a
BU EXP 1330C	3.74b	4.54ab	4.39ab
BU EXP 1330D	4.12ab	4.48ab	3.87b
BU EXP 1330E	4.21ab	4.23ab	3.86b

[†] Clippings were harvested at 7.62 cm at four random locations in each plot.

[‡] Means within columns followed by the same letter are not significantly different at $P \leq 0.05$.