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Effects of Foliar Applied Titanium (Ti) on Quality and Nutrient Uptake of Creeping Bentgrass (Agrostis Stolonifera) on Professional Golf Course Greens

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EFFECTS OF FOLIAR APPLIED TITANIUM (Ti) ON QUALITY AND NUTRIENT UPTAKE OF CREEPING BENTGRASS (*AGROSTIS STOLONIFERA*) ON PROFESSIONAL GOLF COURSE GREENS

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Golf course putting greens typically consist of creeping bentgrass on sandy soils. Creeping bentgrass is mowed at extremely short heights, limiting root growth and making it vulnerable to different pests. Sandy profiles make it difficult for creeping bentgrass to take up nutrients and water. Tytanit® combines sulfur, magnesium, and titanium-ascorbate as a biostimulant to increase chlorophyll content within the plant, increase yields, and assist in fighting biotic and abiotic diseases such as diseases and drought. Previous studies have shown benefits in plant growth, but results have been inconsistent. No previously reported studies have been performed on turfgrass using Tytanit®. Therefore, this study determined the effect of foliar applied titanium to L-93 creeping bentgrass putting greens on engineered sand rooting profiles at two locations in Central Illinois. Two treatment plots and a control plot were studied during this research project. The label rate for horticulture crops (0.07% of total tank volume; 1x) and the label rate for agronomic crops (0.14% of total tank volume; 2x) were both applied and studied during this project. Soil and tissue samples were analyzed throughout the duration of the project. Digital photos were analyzed to test visual chlorophyll differences between the treatment areas. Potassium tissue concentration increased with magnesium, sulfur, and copper tissue concentration with the agronomic rate of Tytanit® at Mounier Golf Training Center at Weibring

Golf Club in Normal, IL. Phosphorus, manganese, and zinc tissue concentration decreased during this time frame. Calcium, magnesium, iron, and manganese tissue concentration increased with the horticultural rate of Tytanit® at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL. Titanium did impact plant growth in this study, but the results were location and nutrient specific, so it is recommended that further research be conducted on this product.

KEYWORDS: chlorophyll content, macronutrients, micronutrients, putting greens, root growth, sandy profiles

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CHAPTER I: THE PROBLEM AND ITS BACKGROUND

The turfgrass industry is one of the largest agricultural industries in the United States (Emmons 2008). California, Texas, Florida, and New York spend more than $5 billion in each state every year on turfgrass research (Emmons, 2008). A study conducted in these states in 2013 found homeowners were willing to spend $25-74 per year on fertilizers for their lawn (Khachatryan et al., 2014). There are approximately 15,000 golf courses in the U.S. alone, decreasing 5.6% since 2006 (Crittenden, 2017). The National Golf Foundation found that nearly 12% of the population over the age of 12 golfs, and that there are more than 30,000,000 golfers in the United States and 60,000,000 worldwide (Emmons, 2008). With the popularity of this sport, it remains important to have sound management techniques in maintaining golf courses, especially the putting greens.

Typically, putting greens are composed of creeping bentgrass and mowed at extremely low heights, which can limit root growth and increases sensitivity to environmental stresses (McCullough et al., 2006). Putting greens also experience large amounts of traffic from golfers constantly walking on the greens, which weakens its recuperative capacity that causes weed invasions (Samaranayake, Lawson, and Murphy, 2008). Thus, improving nutrient use efficiency is economically and agronomically beneficial for the long-term health of putting greens (McCullough et al., 2006).

The Environmental Protection Agency has developed ecologically sound strategies to manage fertility and pests (Balogh and Walker, 1992). Golf courses provide a natural habitat for many animals, including threatened species, and have a direct impact on water sources, especially the putting greens because they are constructed of sandy soils, which are susceptible to nutrient and water loss. (Terman, 1997). Balogh and Walker (1992) suggests that chemical treatment of turfgrass should not be a source of water pollution (surface or groundwater) if managed properly. Large amounts of habitat on golf courses reduces water runoff, irrigation, and chemical inputs (Terman, 1997). Golf courses should be able to reduce these issues by combining environmentally sound measures with Integrated Pest Management (IPM) methods when using pesticides and applying essential nutrients to the turf (Balogh and Walker, 1997).

Modern putting greens are typically constructed using sands to avoid compaction and increase water drainage (Bigelow et al., 2001). Nutrient management is difficult on sand-based greens due to the physical and chemical characteristics of the sand and shallow root zone of the creeping bentgrass (Bigelow et al., 2001). For drainage purposes, creeping bentgrass on putting greens is typically established on sand-based soils, which are prone to nutrient deficiencies and require supplemental fertilization (Rodriguez et al., 2002). Although sands provide favorable physical properties, nutrient retention is often poor and soluble nutrients are prone to leaching (Bigelow et al., 2001).

These sandy soils often require supplemental fertilization because of their low cation exchange capacity (CEC). The CEC of a soil is measured by the amount and type of colloids (clay minerals and organic matter) present (Havlin et al., 2005). CEC is measured in $cmol_c$ per kg^{-1} of soil and is a measure of the quantity of readily exchangeable cations neutralizing negative charge in the soil (Rhoades, 1982). In other words, a soil's CEC shows how well the soil can hold onto cations and water without them leaching or leaving the soil profile. The higher the CEC, the more cations and water the soil can retain. Sands typically have a low CEC, thus they retain little nutrients and water.

The objectives of this study was to…

- Apply a foliar Ti biostimulant on creeping bentgrass on professional golf course putting greens the effect on color and quality.
- Specific measurements included chlorophyll content, visual coloration, and macro- and micronutrient uptake include measuring chlorophyll content of creeping bentgrass on golf course putting greens at Mounier Golf Training Center at Weibring Golf Club, Normal, IL, and Lauritsen/Wohlers Outdoor Golf Practice Facility, Urbana, IL.

The previously mentioned elements have been individually researched, with varying beneficial results, depending on the crop. Thus, if properly managed, their potential to benefit creeping bentgrass on golf course putting greens is likely. However, additional research is needed to determine the effect Ti has on plant growth, specifically on creeping bentgrass.

CHAPTER II: REVIEW OF RELATED LITERATURE

GOLF COURSE INDUSTRY MANAGEMENT

Golf courses are an important part of the turf industry. The popularity of golf in the world continues to grow and the number of golf courses now exceeds 25,000 worldwide (Guzman and Fernandez, 2014; Terman, 1997). More than 100 colleges and universities in the U.S. offer turfgrass classes or complete turfgrass programs (Emmons, 2008). Each state holds turf conferences and field days to help keep turfgrass managers up-to-date on their information and knowledge (Emmons, 2008).

OVERVIEW OF CREEPING BENTGRASS

Creeping bentgrass (*Agrostis stolonifera*) is the most commonly used cool season turfgrass on golf course fairways, tees and putting greens in the U.S. (Elmore et al., 2015) (Emmons, 2008). The quality of a golf course is judged by the condition of its greens (Emmons, 2008). A lot of the important strokes of a round of golf occur on the greens. To put things into perspective, a golf course superintendent held to a tight budget will attempt to keep the greens in excellent shape and give lower priority to fairways and other turf areas (Emmons, 2008). Summer growing conditions can facilitate biotic and abiotic stresses such as diseases and drought stress on creeping bentgrass (Dernoeden, 2013). Many bentgrass diseases are associated with color changes, appear in circular patterns, and can result in a loss of vigor and stand density (Dernoeden, 2013). Turf fungal diseases typically rely on fungicides for control, which can cause environmental concerns (Zhou et al., 2011).

Mowing Creeping Bentgrass

Creeping bentgrass is a very commonly used cool season turfgrass on golf course greens in the transition zone and cool climate areas (Liu and Huang, 2002). With putting greens, low mowing heights lead to increased golf ball speed, which is a common practice (Liu and Huang, 2002). Creeping bentgrass is typically mowed at 0.12 in with a reel mower (Emmons, 2008). When cut this short, creeping bentgrass is highly attractive but becomes shallow rooted and can be severely damaged in the summer (Emmons, 2008; Dernoeden, 2012). However, low mowing heights are generally preferred to maintain surface smoothness in high density cultivars (Dernoeden, 2012).

United States Golf Association (USGA) Sand-Based Greens

The USGA's method of constructing putting greens has served as the industry standard for building greens since it was introduced in 1960 (Moore, 2004). Most of the changes since its introduction have revolved around adjusting the root zone mix (Hummel, 1993). Physical and chemical properties of root zone mixes and methods of putting green construction are critical considerations for improving turf quality (Ok, Anderson, and Ervin, 2003). Sand provides an ideal root zone for bentgrass putting greens due to its particle size, which provides a firm surface for foot traffic and compaction resistance, while remaining highly permeable (Ok, Anderson, & Ervin, 2003). Sands also have low water and nutrient retention properties, even with added peat moss because the peat moss deteriorates in three to four years (Brockhoff et al, 2010).

The USGA funded research projects in the 1950s at Texas A&M and the University of California at Los Angeles to study root zone structures (Hummel, 1993). Studies show that the root zone mix of a putting green should be 85% to 90% sand, with the rest being peat or aggregated clay (Hummel, 1993). Since 1993, more than $1 million has funded 18 projects regarding the slope of the greens, water movement in USGA and California profiles, engineering factors of sand root zones, the impact of inorganic and organic amendments, environmental impact of sand-based greens, and the status of microorganisms in sand-based greens and in fumigated root zones (Moore, 2004).

PRIMARY MACRONUTRIENTS IN TURF

Nitrogen

Perhaps no other nutrient has as much of an impact on golf greens in terms of canopy color, vigor, root-to-shoot ratios, and disease susceptibility than nitrogen (N) (Schlossberg and Schmidt, 2007). Studies show that desired turf color, the mass of the turf clippings, and the percent foliar N all increased with an increase of inorganically applied N fertilizer (Garling and Boehm, 2001). The darker shade of green is more aesthetically pleasing turf (Schlossberg and Schmidt, 2007). In another study, results showed better quality turf after equal applications of N in the NH_4^+ and NO_3^- forms, instead of one or the other (Schlossberg and Schmidt, 2007). For plants, NH_4^+ and NO_3^- are the most important forms of N and are produced from aerobic decomposition of soil organic matter or from addition of N fertilizers (Havlin et al., 2005). However, it is important to remember after sod establishment at least half of the applied nitrogen should be in a slow release form (Schlossberg and Schmidt, 2007). There was another study completed on sand-based greens, during establishment, with nitrogen fertilizer application (Brauen and Stahnke, 1995).

During the first year of establishment, there was a limited root structure, no thatch, and no organic matter, which led to leaching, especially in the fall and spring with increased rainfall (Brauen and Stahnke, 1995). However, hardly any nitrate leached when applied at the standard four pounds total (one pound per application) per 1,000 square feet per growing season (Brauen and Stahnke, 1995). The other excessive nitrate leaching numbers found were involved with over-applying and excessive rainfall; 12 pounds per 1,000 square feet saw much more leaching than eight pounds per 1,000 square feet (Brauen and Stahnke, 1995).

Nitrogen levels on low CEC sandy soils can decrease quickly due to plant uptake and leaching (Johnson, Koenig, and Kopp, 2003). Deficient nitrogen levels have a direct correlation with the chlorophyll production made by bentgrass, which, in turn, has a direct impact on the health of the plant (Johnson, Koenig, and Kopp, 2003). (Razmjoo et al., 2008) showed that a higher mowing height reduces nitrogen levels, so when it comes to increasing nitrogen levels in the plant, inorganic fertilizer is the main way to do so.

Phosphorus

Plants can uptake phosphorus (P) in the inorganic forms $H_2PO_4^-$ and HPO_4^{2-} (Havlin et al., 2005). The most essential function P provides is energy storage and transfer within the plant (Havlin et al., 2005). Another function is P aids in root promotion (Emmons, 2008). As with nitrogen, organic P converts to plant available inorganic P through mineralization and becomes unavailable during immobilization, which occurs with warmer temperatures (Busman et al., 2002). Phosphorus can adsorb to clay particles to reduce leaching, which is seen in fine-textured soils (Havlin et al., 2005). Phosphorus has three pools within the profile- the fixed pool holds the P that is insoluble and therefore unavailable to the plant, the solution pool, which contains the orthophosphate forms (plant available), and the active pool, which replenishes the solution pool (Busman et al., 2017).

With turf, P should be incorporated after application (Emmons, 2008). Most of the P lost from the soil profile is due to water running over the surface causing runoff (Havlin et al., 2005). Because of this, P can be considered a pollutant to water bodies (algae blooms), which is why it is environmentally and economically important to only apply when soil test results show a deficiency (Emmons, 2008). It is important to note many turf areas have adequate P levels because it does not leave the soil profile readily; however, sand-based greens with low CEC could be an exception (Emmons, 2008).

Potassium

Potassium (K) counteracts many of the negative effects of nitrogen such as decreased plant tolerance to cold, heat, drought, and diseases (Emmons, 2008). Potassium is absorbed by plants in the K^+ form and is needed for metabolic (energy making) reactions because of its capacity to activate a multitude of enzymes (Maathuis, 2009). These metabolic processes include photosynthesis, synthesis, and translocation of enzymes (Havlin et al., 2005). Energy from these processes is required for production in carbohydrates, proteins, lipids, oils, vitamins, and other compounds, essential for plant growth (Havlin et al., 2005). Higher K concentrations allow plants to allocate more resources to developing stronger cell walls for preventing pathogen infection and insect attack, and to obtain more nutrients to be used for plant defense and damage repair (Wang et al., 2013). Adequate amounts of K help resist drought damage, maintaining good cell structure to keep the plant healthy and strong (Wang et al., 2013).

Plants exhibit “luxury consumption” with K, absorbing more than they need (Emmons, 2008). Like with other nutrients, sand creates a different environment for K. A lack of response to applied K has been explained by lack of stress due to high amounts of K in the sand (Johnson, Koenig, and Kopp, 2003). Another explanation for lack of response is the inability of the K to adsorb to the sand particles due to low CEC, which leads to subsequent leaching of K through the root zone (Johnson, Koenig, and Kopp, 2003).

Potassium is the second most needed nutrient by turf (Johnson et al., 2003). However, as stated earlier, turf will absorb more K than needed (Emmons, 2008). Turf fertilizers with a 2:1

nitrogen to K ratio are often recommended unless soil tests indicate otherwise (Emmons, 2008). Some studies have shown applications of K to other types of grass showed no benefit, but it is important to note creeping bentgrass being mowed at such short heights is more susceptible to drought, and K can help prevent drought (Wang et al., 2013; Fitzpatrick and Guillard, 2004).

SECONDARY MACRONUTRIENTS

Sulfur

Sulfur (S) is a secondary macronutrient and is primarily absorbed as SO_4^{-2} (Havlin et al., 2005). Sulfur is critical for protein synthesis (Jeschke and Diedrick, 2017). It is taken up primarily as sulfate and required for synthesis of S-containing amino acids, which are essential components of plant proteins that compromise nearly 90% of S in plants (Havlin et al., 2005). In the early spring, a sulfur application may be beneficial as mineralization needs warm weather to take place (Jeschke and Diedrick, 2017). Mineralization is the conversion of S from organic to inorganic, meaning the plant can then use the nutrient. There is a benefit to applying S to young plants or plants with shallow root systems because S can be translocated in the soil profile (Jeschke and Diedrick, 2017).

Calcium

In humans, not having enough calcium (Ca) leads to fragile bones, and this is similar in plant growth, with calcium deficiency leading to the disintegration of cell walls and the collapse of the affected tissues (Hirschi, 2004). When examining the total amount of Ca in plants, the concentration is quite large but its requirement is comparable to the requirement of a micronutrient (Hepler, 2005). However, Ca plays an important role in germination and pollen production (Brewbaker and Kwack, 1963). In a study done, Ca was uniformly distributed along pollen tube walls and the growth of the pollen due to calcium related primarily to the binding of Ca to groups along the pollen wall (Brewbaker and Kwack, 1963).

In another study, elevating Ca levels led to an inhibition in shoot or coleoptile growth, but reducing its concentration promoted cell and tissue elongation (Hepler, 2005). The same study showed low calcium concentrations making membranes more permeable, and if this is true, it is right to believe high calcium concentrations should make the membrane less permeable (Hepler, 2005). Calcium stabilizes cell membranes by connecting various proteins and lipids at membrane surfaces so when these membranes and cell wall weaken, they are susceptible to letting disease pathogens enter the plant (Hirschi, 2004).

While Ca deficiency is uncommon, it is seen in highly leached, unlimed soils (Havlin et al., 2005). Calcium is generally immobile in the plant and is important in enhancing nitrate uptake in the plant as well (Havlin et al., 2005). Ever since the early sixties, plant biologists have been investigating the notion that Ca is crucial for plant development, along with the other macronutrients as well (Hepler, 2005). Macronutrients are considered such because plants require them in large amounts; however, micronutrients, though less demanded, have just as much of a critical role in plant growth and development.

Magnesium

Magnesium is a secondary macronutrient also present in the earth's crust at approximately 2% (Havlin et al., 2005). Even though Mg is a secondary macronutrient, it is an important chlorophyll molecule in plant tissue and helps to activate specific enzyme systems (Kaiser, Rosen and Lamb, 2016). It is also required for carbohydrate metabolism (Havlin et al., 2005). Thus, if Mg is deficient, there will be a shortage of chlorophyll causing stunted growth (Kaiser et al., 2016). Most Midwest soils contain adequate amounts of Mg (Kaiser et al., 2016).

Arid soils show deficiencies. Magnesium is a mobile nutrient, meaning deficiencies would be seen on the lower portion of the plant.

ESSENTIAL MICRONUTRIENTS FOR PLANT GROWTH

Micronutrients are equally important as macronutrients in plant growth; the only difference is micronutrients are required in smaller amounts (Havlin et al., 2005). There are seven essential micronutrients and they combined constitute less than one percent of the dry weight of most plants (Clemson University, 2018). Plants grown in micronutrient deficient soils will exhibit deficiency symptoms just like macronutrients (Havlin et al., 2005). Some forms of these nutrients are more important than others, but understanding the relationships and dynamics among these nutrients is critical for optimizing plant productivity (Havlin et al., 2005).

The physiological interaction and substitution of nutrients with each other in metabolic processes can make it difficult to identify the role of a single nutrient in a disease (Huber and Wilhelm, 1988). Studies have recognized the relationships between manganese (Mn) status of the plant and severity of the disease infecting the plant, and manganese plays a big role (Huber and Wilhelm, 1988). Manganese has been shown to help with production of chlorophyll but excessive amounts have shown to decrease chlorophyll levels (Shenker, Plessner, and Tel-Or 2004).

Iron (Fe) assists in photosynthesis, respiration, and nitrogen assimilation (Raven, 1988). A large portion of the arable land worldwide does not have soil properties that allow sufficient Fe for optimal growth and yield (Buckhout and Schmidt, 2003). Because solution Fe is low compared to calcium, magnesium, and potassium, only a small amount of Fe is adsorbed to the clay particles, meaning only a little adsorbed iron contributes to plant growth (Havlin et al., 2005).

Chlorine (Cl) is primarily involved with maintaining osmotic and ion charge balance, which are important in many biochemical processes in plants (Havlin et al., 2005). Chlorine is also critical for the function of manganese within the plant (photosynthetic production of carbohydrates) (Havlin et al., 2005). For plants to use nutrients efficiently, nutrients accumulate in the vacuole until being transported to growing plant parts; chlorine helps with maintaining balance in the tonoplasts, which are membranes that protect the vacuole (Havlin et al., 2005).

Boron (B) deficiency is viewed in plants more than any other micronutrient, world-wide (Blevins and Lukaszewski, 1998). Deficiencies are typically seen in light-textured soils where the boron can leach in a water-soluble form (Blevins and Lukaszewski, 1998). Boron's primary function is incorporated with plant cell wall structure- cell wall expansion and lignin production with cell wall expansion (Blevins and Lukaszewski, 1998; Havlin et al., 2005).

Zinc (Zn) is required for the production of growth hormones (Havlin et al., 2005). Reduced growth hormone production in plants causes shortening of internodes and smaller than usual leaves (Havlin et al., 2005). Zinc is also involved with chlorophyll synthesis, enzyme activation, and cell wall integrity (Havlin et al., 2005). Deficiencies in grasses can reduce tillering and can be seen as a chlorotic midrib of younger leaves (Havlin et al., 2005).

Soil solution copper (Cu) and plant available Cu are mainly determined by solution pH and the amount of Cu adsorbed to the clay and organic matter surfaces (Havlin et al., 2005). Copper provides structure in regulatory proteins and participates in photosynthetic electron transport, mitochondrial respiration, oxidative stress response, cell wall metabolism, and hormone signaling (Yruela, 2005). Both Cu deficiencies and excess Cu can cause disorders in plant growth and development by adversely affecting important physiological processes in plants (Yruela, 2005).

Besides copper, molybdenum (Mo) is the least abundant essential micronutrient present in most plant tissues (Kaiser et al., 2005). It is often set as the base from which all other nutrients are compared to and measured (Kaiser et al., 2005). Considered a transition element, Mo is required by enzymes that catalyze important reactions within the cell (Mendel, 2011). Molybdenum is used by selected enzymes to carry out redox reactions (Kaiser et al., 2005). However, there is little information on how plants access Mo from the soil and how it is distributed throughout the plant (Kaiser et al., 2005).

Even though nickel (Ni) is essential for plant growth, the amount of Ni required is very low (Chen et al., 2009). It is important to keep the amount of Ni low in plants and the soil solution, because it has been found to be toxic at high levels, limiting root growth (Seregin and Kozhevnikova, 2006). However, a Ni deficiency has been shown to cause an increase in nitrogen uptake, causing necrosis among leaves (Eskew et al., 1984).

BENEFICIAL NUTRIENTS FOR PLANT GROWTH

Beneficial elements are not classified as essential for plant growth and development (Kaur et al., 2015). These elements are not critical for plants but have the potential to improve plant growth and yield (Kaur et al., 2015). Beneficial elements enhance resistance to abiotic stresses (drought, salinity, high temperatures, cold temperatures, ultraviolet stress, nutrient toxicity, and nutrient deficiency (Kaur, et al., 2015).

Titanium (Ti) is the tenth most abundant element in the earth and is present in the soil at relatively high concentrations (57% by weight of the crust); however, it is insoluble at pH ranges of 4-8, which is the range most plants need because most nutrients are available in that pH range (Carvajal and Alcaraz, 1998; Lyu et al., 2017). Titanium content has been shown to intensify plant growth and development, as well as cause increased chlorophyll content (Tlustos et al., 2005). The results have varied from plant-to-plant, as well as how much Ti benefits the plant, and, in general, if it does noticeably at all. To the author's knowledge, no reported studies have been researrched on turfgrass using foliar applied Ti, but those that have been completed have mainly focused on various agronomic and horticultural crops, all showing benefits for the most part, but varying results. Another study done tested annual bedding plants and those results fluctuated from plant-to-plant (Whitted-Haag et al., 2014).

Tytanit® is a liquid biostimulant that combines titanium, magnesium, and sulfur to create a biostimulant that aids in plant growth by increasing chlorophyll content and helping resist biotic and abiotic disease stress. It is composed of 10% sulfur trioxide, five percent magnesium oxide, and 0.85% titanium-ascorbate. Tytanit® provides the previously mentioned nutrients in soluble forms and is made by INTERMAG in Poland.

SOIL AND PLANT TISSUE LABORATORY ANALYSIS

Farmers and growers soil test mainly to determine fertilizer and lime requirements (Jones, Jr., 2001). The other main reason soil samples are taken is to determine if there would be a profitable response to a fertilizer application (Jones, Jr., 2001). Plant tissue testing is useful in helping determine nutrient status within the plant and diagnosing nutrient deficiencies (University of Connecticut). This allows growers to have the most efficiently effective nutrient management program (University of Connecticut). Analysis by inductively coupled plasma (ICP) has become more popular in labs due to its ability to measure multiple elements, meaning it's very versatile and efficient (Pittman et al., 2007).

DIGITAL ANALYSIS

Near-ground remote sensing is becoming increasingly important in modern agriculture production (Jia et al., 2014). Ground-based observations of crop growth provide fast, real-time, non-destructive, automatic, and relatively inexpensive information about crop status (Jia et al., 2014). This information can significantly increase yields by allowing growers to properly time cultivation, fertilizer application, irrigation, pest control, and harvest (Jia et al., 2014).

FOLIAR APPLICATIONS OF FERTILIZERS

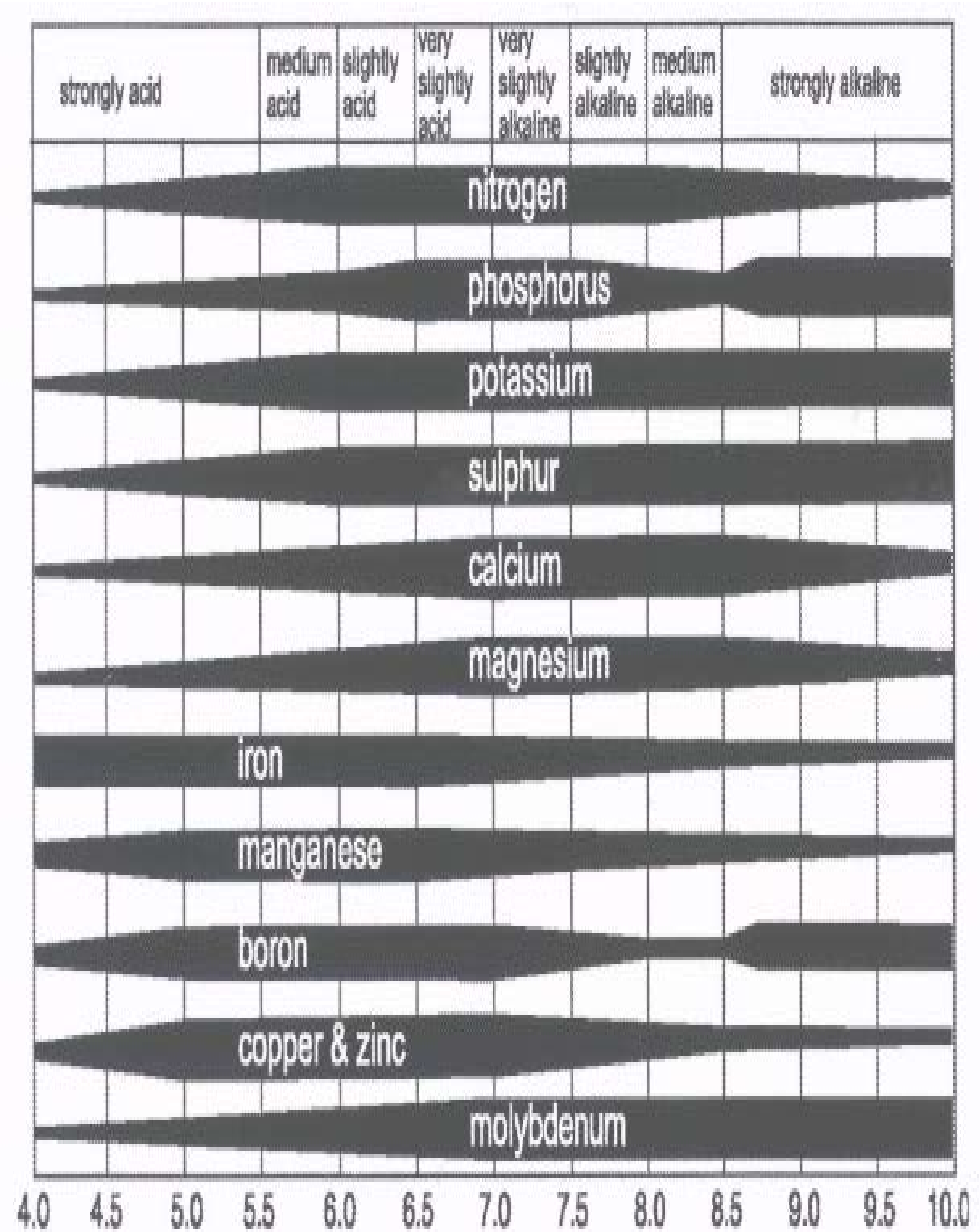
Foliar fertilization is the process of nutrient uptake through the foliage or other aerial parts of the plant (Stiegler et al., 2010). All 16 plant nutrients have been reported to be absorbed by leaves (Liu et al., 2003). Using foliar fertilizers has seen an upward trend for all levels of turfgrass management, including home lawns and sports turf, especially golf courses (Liu et al., 2003; Stiegler et al., 2010). Total fertilizer input may be reduced by using foliar fertilization (Liu et al., 2003). Recent surveys of Arkansas golf course superintendents show that nearly all superintendents use foliar fertilization on at least some area of the golf course (Stiegler et al., 2010). Micronutrient deficiencies may limit crop yields even though small amounts of each nutrient are required by plants (Martens and Westerman, 1991). Foliar applications of fertilizers can help change that. Foliar fertilization can complement soil fertilization (Fageria et al., 2009).

Nutrient uptake by leaf tissue is more affective the longer the nutrient solution remains in the form of a fine film on the leaf surface, which means applying a foliar fertilizer on a hot, humid day will make absorption tough (Mengel and Kirby, 1987). Nutrient concentration and day temperature should be optimal to avoid leaf burning and the fertilizer source should be soluble in water to be more effective (Fageria et al., 2009). Cool season grasses can absorb foliar fertilizers better than warm season grasses due to a higher concentration of stomates (Hull and Kopec, 2001). The process of nutrient uptake by leaf cells is at the very least comparable to that of root cell absorption- the transport of the nutrients through the biological membrane, the plasmalemma, is the main process (Mengel and Kirby, 1987). The rate of uptake is regulated by diffusion of the nutrients from the water film on the leaf surface through the cuticle and cell wall material to the plasmalemma (Mengel and Kirby, 1987). Foliar application is particularly useful under certain conditions restricting nutrient uptake, and it is important to note the maximum effect of one particular nutrient can only be expected if the concentration of the other plant nutrients is adequate (Mengel and Kirby, 1987).

Several studies have been done testing foliar fertilizer applications on sports turf, typically of N, P, and K. One test showed an absorption rate of 30% to 60% of the N applied and 43% to 74.8% of the P and K applied (Liu et al., 2003). The rest of the percentages can be left in the soil, lost by the removal of clippings, or stuck in the thatch layer; however, it is important to note that unabsorbed liquid fertilizer still has a better chance of being available to the plant than granular fertilizers because liquid fertilizers are already dissolved (Liu et al., 2003). Another test was done on creeping bentgrass specifically at the University of Arkansas, and foliar N was applied with no irrigation for 24 hours to test the true absorption rate of the leaves (Stiegler et al., 2010). The absorption rate ranged from 24-57% in the first hour after treatment and 76% of the N was absorbed in the first 24 hours during the month of May, which is the month with the highest absorption rate (Stiegler et al., 2010). A study done at Clemson University showed bentgrass absorption being the highest when the fertilizer was applied as 100% liquid (Totten, 2006).

Foliar fertilization can result in more uniform growth and more consistent putting green conditions (Stiegler et al., 2010). In today's agricultural world, environmental practices are a growing concern, and it is true that foliar applications are more environmentally sound practices than granular fertilizers (Liu et al., 2003).

Figure 1. pH Effect on Nutrient Uptake (Vista and Brasnet, 2015)



COMMON DISEASES OF BENTGRASS GREENS

Creeping bentgrass is prone to several diseases (Cook, 2008). Dollar spot, brown patch, and pythium blight are seen nationwide (Cook, 2008). Fairy ring is seen more on sandy soils due to thatch and root environment (Cook, 2008). Creeping bentgrass is susceptible to diseases by hyphae entering through the stomata and through mowing wounds (Emmons, 2008). Fungicides are cost-effective because of the value level of greens; however, a reduction in fungicides would be beneficial because of how intensely used golf courses are during the summer as well as golfers being in close contact with the turf (Goodman and Burpee, 1991).

Dollar Spot

Creeping bentgrass is highly susceptible to dollar spot (Belanger, Bonos, and Meyer, 2004). There is a wide range of susceptibility among current cultivars (Belanger, Bonos, and Meyer, 2004). Genetic resistance is an important control strategy that can reduce fungicide use (Bonos, 2006). The genetic mechanism of dollar spot resistance in turfgrasses is not fully understood (Bonos, 2006). Mowing and dew removal can greatly reduce the chances of seeing dollar spot on creeping bentgrass (Ellram et al., 2006). Removing the dew daily reduced the chances of seeing dollar spot compared to removing the dew every other day (Ellram et al., 2006). There were no differences in disease control indicated between sharp and dull blades when it came to mowing (Ellram et al., 2006). Dollar spot activity begins at 60 degrees Fahrenheit and is optimum at 70-80 degrees Fahrenheit (Emmons, 2008). The first symptoms are straw-colored bands on the leaves and on closely-mowed turf, the first observable signs are when the spots on the turf are the size and shape of a silver dollar (Emmons, 2008).

Brown Patch

Creeping bentgrass is one of the most susceptible grasses to brown patch (Emmons, 2008). Curative applications of fungicides on turf infected with brown patch do not always control the disease (Settle, Frye, and Tisserat, 2001). Brown patch develops rapidly, with some plots exceeding 10% of the plot within the first 24 hours (Settle, Frye, and Tisserat, 2001). Disease activity begins at 15 degrees Celsius but is greatest between 27 and 32 degrees Celsius (Emmons, 2008). Somewhat circular, light brown patches ranging from a few inches to several feet across the turf will appear (Emmons, 2008). When the grass is wet, grayish black mycelia may be observed around the edge of the patch (Emmons, 2008). Dew removal can help prevent this disease as well as not overwatering the turf and not over fertilizing with nitrogen fertilizers (Emmons, 2008).

Pythium Blight

There is probably no other disease that can devastate a turf area like pythium blight (Emmons, 2008). Entire turf stands can be destroyed in less than 24 hours when conditions are optimal (27- 32 degrees Celsius, cloudy, wet, rainy weather) (Emmons, 2008). On high value turf such as golf course putting greens, preventative fungicides may be economically justified ("Pythium blight," 2017). On fairway-height bentgrass, the first symptoms appear as irregularly shaped, water-soaked greasy patches up to four inches in diameter (Kennelly, 2008). Leaves appear water-soaked at first, then shriveled ("Pythium blight," 2017). Patches fade to a light brown or gray color (Kennelly, 2008). Groups of spots frequently join together and can even appear in streaks (Kennelly, 2008). Pattern and presence of the streaks determined by the flow of water ("Pythium blight," 2017). Typically, temperatures between 30-35 degrees Fahrenheit and high humidity will trigger this disease (Kennelly, 2008). Sometimes in the early morning, especially with high humidity, a cottony-looking white mycelium is present on the leaf tissue, which is why this disease is also called "cottony blight" (Emmons, 2008). Moderate fertilizer applications and adequate drainage can help prevent Pythium blight ("Emmons, 2008).

Fairy Ring

Fairy rings are partial or complete circular bands of grass that are darker green and faster growing than the remainder of the turf (Emmons, 2008). The circles are initially one foot or less in diameter but expand in size year after year, reaching up to several hundred feet in diameter ("Fairy Ring," 2016). The organisms that cause fairy rings feed on organic matter in the soil (Emmons, 2008). They release chemicals that stimulate plants to grow faster and become darker (Emmons, 2008). If the conditions are wet enough, mushrooms can appear along the circular pattern (Emmons, 2008). Turf is not typically injured by fairy rings, but can be killed if the fungi secrete toxic compounds or if the layer of mycelia becomes so thick that water cannot penetrate to the roots (Emmons, 2008). The source of fairy ring infestations is unclear ("Fairy Ring," 2016). Sterilization or fumigation of the root zone mix has not been effective in controlling fairy ring establishment ("Fairy Ring," 2016). Power raking or vertical mowing to remove excess thatch will help to minimize fairy rings ("Fairy Rings," 2016). Golf course superintendents should aerate and topdress putting greens regularly to prevent thatch buildup and maintain soil aeration ("Fairy Ring," 2016). It's important to avoid extremes in soil moisture (too wet, too dry) and to apply adequate nitrogen and maintain adequate nutrient levels ("Fairy Ring," 2016). Applying extra nitrogen to the surrounding areas can help mask the darker green color of the infected turf (Emmons, 2008). Fungicides are most effective for fairy ring control when used as a preventative fungicide ("Fairy Ring," 2016). Curative applications have little to no effect because the symptoms are caused by a change in the soil environment and fungicides do nothing to change the soil environment (“Fairy Ring,” 2016).

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CHAPTER III: EFFECTS OF FOLIAR APPLIED TITANIUM (TI) ON QUALITY AND NUTRIENT UPTAKE OF CREEPING BENTGRASS (*AGROSTIS STOLONIFERA*) ON PROFESSIONAL GOLF COURSE GREENS

ABSTRACT

Golf course putting greens typically consist of creeping bentgrass on sandy soils. Creeping bentgrass is mowed at extremely short heights, limiting root growth and making it vulnerable to different pests. Sandy profiles make it difficult for creeping bentgrass to take up nutrients and water. Tytanit® combines sulfur, magnesium, and titanium-ascorbate as a biostimulant to increase chlorophyll content within the plant, increase yields, and assist in fighting biotic and abiotic diseases such as diseases and drought. Previous studies have shown benefits in plant growth, but results have been inconsistent. No previously reported studies have been performed on turfgrass using Tytanit®. Therefore, this study determined the effect of foliar applied titanium to L-93 creeping bentgrass putting greens on engineered sand rooting profiles at two locations in Central Illinois. Two treatment plots and a control plot were studied during this research project. The label rate for horticulture crops (0.07% of total tank volume; 1x) and the label rate for agronomic crops (0.14% of total tank volume; 2x) were both applied and studied during this project. Soil and tissue samples were analyzed throughout the duration of the project. Digital photos were analyzed to test visual chlorophyll differences between the treatment areas. Potassium tissue concentration increased with magnesium, sulfur, and copper tissue concentration with the agronomic rate of Tytanit® at Mounier Golf Training Center at Weibring Golf Club in Normal, IL. Phosphorus, manganese, and zinc tissue concentration decreased during this time frame. Calcium, magnesium, iron, and manganese tissue concentration

increased with the horticultural rate of Tytanit® at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL. Titanium did impact plant growth in this study, but the results were location and nutrient specific, so it is recommended that further research be conducted on this product.

KEYWORDS: macronutrients, micronutrients, sandy profiles, chlorophyll content, putting greens, root growth

INTRODUCTION

Golf courses are an important part of the turf industry. The popularity of golf in the world continues to grow and the number of golf courses now exceeds 25,000 worldwide (Guzman and Fernandez, 2014; Terman, 1997). Creeping bentgrass (*Agrostis stolonifera*) is the most commonly used cool season turfgrass on golf course fairways, tees and putting greens in the U.S. (Elmore et al., 2015; Emmons, 2008).

Creeping bentgrass is a very commonly used cool season turfgrass on golf course greens in the transition zone and cool climate areas (Liu and Huang, 2002). On putting greens, lower mowing heights are a common practice to increase golf ball speed (Liu and Huang, 2002). Creeping bentgrass is typically mowed at 0.30 cm with a reel mower (Emmons, 2008). When cut this short, creeping bentgrass is highly attractive but becomes shallow rooted and is more prone to damage and reduced playing quality (Emmons, 2008; Dernoeden, 2012). However, low mowing heights are generally preferred to maintain surface smoothness in high density cultivars (Dernoeden, 2012).

Sand provides an ideal root zone for bentgrass putting greens due to its particle size, which provides a firm surface for foot traffic and compaction resistance, while remaining highly permeable (Ok, Anderson, and Ervin, 2003). Sands also have low water and nutrient retention properties, even with added peat moss because the peat moss deteriorates in three to four years (Brockhoff et al, 2010). In addition, sandy soils often need supplemental fertilization because of their low cation exchange capacity (CEC). The CEC of a soil is determined by the amount and type of colloids in a soil (Havlin et al., 2005). Colloids consist of organic matter and clay particles less than 0.001 mm in diameter (Havlin et al., 2005). CEC is measured in milliequivalents per $cmol_c$ per kg^{-1} of soil and is a measure of the quantity of readily exchangeable cations neutralizing negative charge in the soil (Rhoades, 1982). CEC describes the potential of a soil to hold onto positively charged nutrients (cation) and water without them leaching or leaving the soil profile. The higher the CEC, the more nutrients and water the soil can retain. Sands typically have a low CEC, thus they retain fewer nutrients and water.

Sixteen elements have been identified as essential for plants to complete their life cycle. Of these elements, carbon, hydrogen, and oxygen generally come from carbon dioxide and water. The atmospheric concentration of CO_2 is currently approximately 400 ppm. Studies evaluating CO_2 fertilization have shown mixed results in enhancing plant groth and are dependent on plant species, temperature, and the availability of other plant essential elements. While soil water content can vary widely, plant growth tends to be optimal at field capacity and decreases above and below this level.

Perhaps no other nutrient has as much of an impact on golf greens in terms of canopy color, vigor, root-to-shoot ratios, and disease resistance than nitrogen (N) (Schlossberg and Schmidt, 2007). Nitrogen levels can decrease quickly due to leaching and low CEC of sandy soils (Johnson, Koenig, and Kopp, 2003). Nitrogen deficiencies show a direct correlation in chlorophyll production synthesized by bentgrass, which, in turn, has a direct positive impact on the health of the plant (Johnson, Koenig, and Kopp, 2003).

Phosphorus (P) is critical for plant growth and development because it provides energy storage and transfer within the plant (Havlin et al., 2005). Phosphorus is also essential for optimal root growth and deficiencies can drastically reduce plant growth (Emmons, 2008). It is important to note many turf areas generally have adequate P levels because it does not leave the soil profile readily; however, sand-based golf greens could be an exception (Emmons, 2008).

Adequate amounts of potassium (K) are known to improve plant drought resistance, which keeps plants healthy and strong (Wang et al., 2013). A lack of response to applied K has been observed and explained by lack of stress on the plant due to high amounts of K initially present in the sand (Johnson, Koenig, and Kopp, 2003). Another explanation for lack of response to K fertilization is the inability of the K to adsorb to the sand particles due to low CEC, which can lead to subsequent leaching of K through the root zone (Johnson, Koenig, and Kopp, 2003). It is important to note that creeping bentgrass managed at short growing heights is more susceptible to drought (Wang et al., 2013; Fitzpatrick and Guillard, 2004). However, K fertilizer has been shown to improve creeping bentgrass drought resistance on golf greens (Wang et al., 2013; Fitzpatrick and Guillard, 2004).

Calcium (Ca) stabilizes cell membranes by connecting various proteins and lipids at membrane surfaces (Hirschi, 2004). Plants growing under Ca deficiencies are more susceptible to disease pathogens (Hirschi, 2004). While Ca deficiency is uncommon, it has been observed in highly leached, unlimed soils (Havlin et al., 2005).

Magnesium is a secondary macronutrient that is present in the earth's crust and absorbed by plant roots as Mg^{2+} (Havlin et al., 2005). Even though Mg is a secondary macronutrient, it is an important chlorophyll molecule in plant tissue and helps to activate specific enzyme systems (Kaiser, Rosen and Lamb, 2016). It is also required for carbohydrate metabolism (Havlin et al., 2005). Thus, when Mg is deficient, there is a shortage of chlorophyll causing stunted growth (Kaiser et al., 2016). Most Midwest soils contain adequate amounts of Mg (Kaiser et al., 2016). Arid soils tend to show deficiencies. Magnesium is a mobile nutrient, meaning deficiencies would be seen on the lower portion of the plant.

Sulfur (S) is also a secondary macronutrient and is primarily absorbed as SO_4^{-2} (Havlin et al., 2005). It is taken up primarily as sulfate and required for synthesis of S-containing amino acids, which are essential components of plant proteins (Jeschke and Diedrick, 2017) that compromise nearly 90% of S in plants (Havlin et al., 2005). In the early spring, an application of sulfur may be beneficial as mineralization needs warm weather to take place (Jeschke and Diedrick, 2017). Mineralization is the conversion of S from organic to inorganic sulfate, which the plant can use. There is a benefit to applying S to young plants or plants with shallow root systems because S can be translocated out of the root zone, causing a deficiency (Jeschke and Diedrick, 2017).

Manganese (Mn) has been shown to help with production of chlorophyll but excessive amounts have a toxic effect, decreasing chlorophyll levels (Shenker, Plessner, and Tel-Or, 2004). Iron (Fe) assists in photosynthesis, respiration, and nitrogen assimilation (Raven, 1988). Chlorine (Cl) is critical to aid Mn with the photosynthetic production of carbohydrates in plants (Havlin et al., 2005). For plants to use nutrients efficiently, nutrients accumulate in the vacuole until being transported to growing plant parts; Cl helps with maintaining balance in the tonoplasts, which are membranes that protect the vacuole (Havlin et al., 2005). Worldwide, boron (B) deficiency is observed in plants more than any other micronutrient, (Blevins and Lukaszewski, 1998). Deficiencies are typically seen in light-textured soils where the B can leach in a water-soluble form (Blevins and Lukaszewski, 1998). Boron assists with plant cell wall structure development, cell wall expansion, and lignin production with cell wall expansion (Blevins and Lukaszewski, 1998; Havlin et al., 2005). Zinc (Zn) is required for the production of growth hormones (Havlin et al., 2005). Zinc also enhances chlorophyll synthesis, enzyme activation, and cell wall integrity (Havlin et al., 2005). Copper (Cu) provides structure in regulatory proteins, improves photosynthetic electron transport, mitochondrial respiration, oxidative stress response, cell wall metabolism, and hormone signaling (Yruela, 2005). Considered a transition element, molybdenum (Mo) is required by enzymes that catalyze important reactions within the cell (Mendel, 2011). Nickel (Ni) deficiency has been shown to increase nitrogen uptake, causing necrosis among leaves (Eskew et al., 1984).

Although not an essential element, there is evidence to indicate that titanium (Ti) is a beneficial element. It is the tenth most abundant element in the earth, is available as Ti^{2+}, Ti^{3+}, and Ti^{4+}, and is present in the soil at relatively high concentrations (57% by weight of the crust); however, it is insoluble at the pH range of 4 to 8, which is considered the optimal range for plant growth because most nutrients exhibit optimal availability in this pH range (Carvajal and Alcaraz, 1998; Lyu et al., 2017). Titanium content has been shown to intensify plant growth and development, as well as cause increased chlorophyll content (Tlustos et al., 2005). However, results have varied from plant-to-plant, as well as how much Ti benefits the plant. No reported studies have been published on turfgrass evaluating foliar applied Ti, but there have been studies completed analyzing various agronomic and horticultural crops. Another study published tested annual bedding plants and growth and quality effects fluctuated from plant-to-plant (Whitted-Haag, et al., 2014).

Tytanit® is a liquid fertilizer that combines titanium, magnesium, and sulfur to create a fertilizer that aids in plant growth by increasing chlorophyll content and helping resist biotic and abiotic disease stress. It is composed of 10% sulfur trioxide, five percent magnesium oxide, and 0.85% titanium-ascorbate. Tytanit® provides the previously mentioned nutrients in soluble forms and is made by INTERMAG in Poland.

All 16 essential plant nutrients have been reported to be absorbed by leaves (Liu et al., 2003). The use of foliar fertilizers has increased for turfgrass management, including home lawns and sports turf, especially golf courses (Liu et al., 2003; Stiegler et al., 2010). Total fertilizer input may be reduced by using foliar fertilization (Liu et al., 2003). Cool season grasses can absorb foliar fertilizers better than warm season grasses due to a higher concentration of stomates in the leaves (Hull and Kopec, 2001). The process of nutrient uptake by leaf cells is at the very least comparable to that of root cell absorption (Mengel and Kirby, 1987). The transport of the nutrients through the biological membrane, the plasmalemma, is the main process (Mengel and Kirby, 1987). It is important to note that unabsorbed liquid fertilizer still has a better chance of being available to the plant than granular fertilizers because liquid fertilizers are already dissolved and readily available for leaf and root absorption (Liu et al., 2003).

MATERIALS AND METHODS

In order to assess the effect of a titanium biostimulant product on creeping bentgrass growth and quality, applications were made to sand-based putting greens using a split plot experimental design (Little and Hills, 1978). The main plots were the 1x Tytanit® rate (label horticulture) treatment, the 2x Tytanit® (label agronomic) treatment, and the untreated control treatment. Sub plots were the sampling dates over time for soil and tissue nutrient analysis and digital image analysis. Strips of each treatment were made on turf surfaces and soil, tissue, and digital images were replicated four (4) times within each strip. Research was conducted in two (2) separate locations; 1) Mounier Golf Training Center at Weibring Golf Club in Normal, IL and at the 2) Lauritsen/Wohlers Outdoor Golf Practice Facility in Champaign, IL. The greens chosen at each location were approximately 3,000 square feet in size.

Titanium treatments consisted of the product label rate (0.07% of total tank volume for horticulture crops), doubled the product label rate (0.14% of total tank volume for the agronomic rate), and an untreated control plot. (Tytanit®, Intermag, Olkusz, Poland) was applied along with a non-ionic surfactant (Spreader Sticker, Lesco, Cleveland, Ohio) to the horticulture (1x) treatment plot and agronomic (2x) treatment plot at 0.5 liters of surfactant per 379 liters of water using sprayer models (Smithco Spraystar 3180, John Deere HD 200) going one direction and mowed the plots (John Deere 180E, John Deere 220E) going in the same direction to collect the clippings. Clipping were collected during mowing. There was a 1.5 m wide buffer zone between each research plot. Each individual plot was 7.62 m long and 1.5 m wide. The total plot was 7.62 m long and 22.86 m wide at each location.

Soil samples were collected from each of the twenty-four subsampling locations before the Tytanit® applications and at two and four weeks after the application for a total of three soil samples per subsampling location. Three (3) soil tests per subsampling locations x twenty-four (24) subsampling locations = 72 total soil samples. Tissue samples were collected individually from reel mower clippings of each subsampling location with the treatment plots prior to the Tytanit® applications, and then every three (3) days over a six (6) week period. There were twelve (12) total tissue analysis samples per subsampling location. Twelve (12) tissue tests per subsampling locations x twenty-four (24) subsampling locations = 288 total tissue samples. Soil and tissue samples were analyzed for elemental content by GMS Labs in Cropsey, IL using Inductively Coupled Plasma (ICP) analysis.

Chlorophyll Analysis- Tissue Extraction

A key component of this project was measuring chlorophyll levels in the plant tissue. Leaf tissue from each mowing was assessed for chlorophyll content using the Lichtenthaler Method (Lichtenthaler, 1987). Harvested plant tissues were frozen at -20° C, until analyzed. The process required 0.5 g of fresh tissue. To begin the extraction, the plant tissue sample was soaked in 20 mL of ethanol in a mortar and pestle. The addition of approximately 1 g of sand aided in grinding the tissue to rupture the cell walls. The sand was sea sand purchased from (Fisher Scientific, Houston, TX). The physical and chemical approaches served to bleach the tissue. Once the tissue was bleached, it was transferred into a graduated cylinder with the addition of another 30 mL of ethanol. The solution was stirred for 1 minute by twisting my wrist and then transferred to a centrifuge tube where it was rotated for three minutes. Once centrifugation was complete, an aliquot was transferred pipette dropper to a spectrophotometer tube that was placed in the spectrophotometer at 470 nm wavelengths, 649 nm wavelengths, and 664 nm wavelengths. These three readings were used to determine the chlorophyll concentration number. The higher the number correlates with more chlorophyll in the tissue.

Digital Analysis

To visually evaluate chlorophyll content, two pictures were obtained from every treatment rep before application and every three days following application using a Canon EOS Rebel T6 (Tokyo, Japan). Pictures were analyzed using Turf Analyzer (Karcher et al., 2017) software to compare plant chlorophyll content between the treatments. The purpose of this portion of the project was to visually test chlorophyll content for general health of the turf but also because dark green turf is less desirable to golfers.

Chlorophyll Content

At Weibring, the control plot had a higher chlorophyll concentration than the treated areas prior to the Tytanit® application. Following the application, the agronomic rate (2x) plot had the highest concentration among the three plots through July 18th (five weeks). At Lauritsen/Wohler's, the control plot had a higher chlorophyll concentration than the treated areas prior to the Tytanit® application. Following the application, the horticultural rate (1x) was the highest concentration through July 4th (two and a half weeks). Chlorophyll content in previous research has varied from plant-to-plant. (Whitted-Haag et al., 2014) found Ti applications to have linear increases and decreases in chlorophyll content, depending on the plant. The results were inconsistent.

Tissue Analysis

These research study results agree with previous research in foliar titanium having an impact on plant growth. Results have varied depending on the individual project and the individual plants being researched. This project evaluated the same soil type (sandy), same creeping bentgrass cultivar (L-93), but two separate locations within Central Illinois to complete this project. By doing this, we feel results will be beneficial to golf course superintendents throughout Central Illinois.

Tytanit® was applied the same day at both locations. Mounier Golf Training Center at Weibring Golf Club in Normal received a 23-0-23 fertilizer three days following the Tytanit® application. The potassium tissue concentration immediately jumped in the agronomic rate treated plot. This increase in concentration lasted for only two days following the 23-0-23 liquid application, which was three days after the Tytanit® application. Essentially, Tytanit® made the fertilizer application more efficient in nutrient uptake compared to the other two plots in the study. However, with the application, there was a decrease in calcium and iron concentration in both treated plots compared to the control plot. At Lauritsen/Wohler's Outdoor Golf Practice Facility in Urbana, there was a delayed response to the Tytanit®. No fertilizer was applied during the time frame of the research project. However, on day 10 following the Tytanit® application, there was an increase in calcium and magnesium concentration but only for the horticultural rate. Four days after this increase, nutrient concentration levels decreased back to the amount they were before the dramatic increase. (Carvajal and Alcaraz, 1998) found consistent magnesium uptake in cereal grains after a Ti application. (Alcaraz-Lopez et al., 2004) saw increased calcium uptake, which led to branch elongation, flowering, fruit set intensities, and fruit size studying peach trees.

STATISTICAL ANALYSIS

Data was subjected to analysis of variance (ANOVA) and regression to test the significance of main treatment effect using SPSS statistical software. (IBM SPSS Statistics 21, Armonk, North Castle, New York).

RESULTS AND DISCUSSION

Results varied by location. Mounier Golf Training Center at Weibring Golf Club saw an increased K uptake along with Mg, S, and Cu with the agronomic rate application of Tytanit®. The enhanced nutrient stimulation was observed for only two days following the 23-0-23 liquid fertilizer that was applied three days following the Ti application. During this time frame, P, Mn, and Zn tissue concentration decreased. Ca, Mg, Fe, and Mn uptake increased at Lauristen/Wohler's Outdoor Golf Practice Facility but not until 10 days following the Ti application. During this time frame, K tissue concentration decreased. The nutrient stimulation lasted four days following that. Previous research had shown benefits and drawbacks to nutrient uptake and chlorophyll content, as well as other factors that were tested in other projects. There was an increase in nutrient stimulation following a 23-0-23 liquid fertilizer applied at Weibring and due to the compatibility of Tytanit® with numerous other fertilizers and pesticides, it could make sense to apply Tytanit® with those fertilizers and/or pesticides to make nutrient stimulation more efficient.

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Table 1. Mean Value[z] and Standard Deviation for Leaf Tissue Macronutrient Content of Creeping Bentgrass (*Agrostis stolonifera*) in the Control Plot at Mounier Golf Training Center at Weibring Golf Club, Normal, IL.

DAT[y]	% Tissue Concentration				
	Ca	K	Mg	P	S
-1	0.8 ± 0.2	1.6 +/- 0.2	0.4 +/- 0.1	0.4 +/- 0.0	0.4 +/- 0.0
2	0.9 ± 0.1	4.5 +/- 0.7	1.9 +/- 0.2	0.3 +/- 0.0	3.2 +/- 0.5
6	0.9 ± 0.1	1.9 +/- 0.3	0.7 +/- 0.1	0.3 +/- 0.1	0.9 +/- 0.1
9	1.3 +/- 0.4	1.1 +/- 0.1	0.6 +/- 0.2	4.9 +/- 1.0	0.6 +/- 0.1
13	0.9 +/- 0.3	2.2 +/- 0.1	0.5 +/- 0.1	0.9 +/- 0.1	0.6 +/- 0.0
16	1.1 +/- 0.4	2.0 +/- 0.2	0.6 +/- 0.2	0.7 +/- 0.1	0.5 +/- 0.0
20	0.8 +/- 0.5	2.3 +/- 0.5	0.4 +/- 0.2	0.6 +/- 0.1	0.4 +/- 0.1
23	0.9 +/- 0.2	2.4 +/- 0.1	0.4 +/- 0.1	0.7 +/- 0.0	0.5 +/- 0.0
28	0.9 +/- 0.3	2.1 +/- 0.2	0.5 +/- 0.1	0.5 +/- 0.0	0.4 +/- 0.0
31	1.3 +/- 0.6	2.1 +/- 0.1	0.7 +/- 0.2	0.6 +/- 0.0	0.4 +/- 0.0
35	1.8 +/- 0.8	2.0 +/- 0.4	0.8 +/- 0.3	0.4 +/- 0.3	0.3 +/- 0.1
38	1.0 +/- 0.4	2.1 +/- 0.2	0.5 +/- 0.2	0.7 +/- 0.1	0.3 +/- 0.0
Contrast[x]					
Linear	NS	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS	NS

[z] Means are of four replications of an homogenous tissue sample removed from a plot 7.62 m long and 1.5 m wide.
[y] DAT=days after treatment. Experimental sampling occurred from June 19 to July 28, 2017.
[x] Significance for linear and quadratic orthogonal contracts. NS = Non-significant.

Table 2. Mean Value[z] and Standard Deviation for Leaf Tissue Micronutrient Content of Creeping Bentgrass (*Agrostis stolonifera*) in the Control Plot at Mounier Golf Training Center at Weibring Golf Club, Normal, IL.

DAT[y]	Tissue Concentration ppm				
	B	Cu	Fe	Mn	Zn
-1	19.7 ± 1.7	11.5 ± 1.0	1378.3 ± 546.7	86.0 ± 32.9	37.8 ± 4.0
2	23.7 ± 1.2	11.0 ± 7.7	879.7 ± 169.9	60.0 ± 1.7	19.8 ± 3.1
6	31.8 ± 5.5	13.5 ± 2.1	1221.3 ± 219.3	73.3 ± 13.2	27.3 ± 4.4
9	58.9 ± 12.6	32.2 ± 9.4	5037.8 ± 593.8	203.4 ± 20.3	210.2 ± 70.2
13	72.7 ± 11.2	15.4 ± 1.5	1538.0 ± 606.4	181.4 ± 62.4	58.9 ± 14.6
16	19.9 ± 2.1	14.5 ± 1.4	1395.3 ± 714.4	149.8 ± 5.1	39.7 ± 7.3
20	23.5 ± 2.9	13.2 ± 2.8	834.5 ± 535.0	94.2 ± 9.3	27.6 ± 4.2
23	36.4 ± 1.2	17.3 ± 0.8	932.5 ± 389.4	124.4 ± 35.6	34.7 ± 6.6
28	27.5 ± 3.3	14.8 ± 0.7	1342.3 ± 756.7	87.3 ± 19.3	24.0 ± 2.0
31	22.5 ± 1.2	14.4 ± 0.8	1174.0 ± 506.2	106.6 ± 54.7	26.4 ± 2.0
35	26.4 ± 2.0	12.8 ± 2.1	2036.3 ± 1080.7	118.9 ± 47.5	25.6 ± 2.8
38	24.7 ± 2.0	18.0 ± 2.2	1123.8 ± 547.4	121.0 ± 10.4	26.3 ± 3.9
Contrast[x]					
Linear	NS	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS	NS

[z] Means are of four replications of an homogenous tissue sample removed from a plot 7.62 m long and 1.5 m wide.
[y] DAT=days after treatment. Experimental sampling occurred from June 19 to July 28, 2017.
[x] Significance for linear and quadratic orthogonal contracts. NS = Non-significant.

Table 3. Mean Value[z] and Standard Deviation for Leaf Tissue Macronutrient Content of Creeping Bentgrass (*Agrostis stolonifera*) in the Horticulture Treatment Plot (1x) at Mounier Golf Training Center at Weibring Golf Club, Normal, IL.

DAT[y]	% Tissue Concentration				
	Ca	K	Mg	P	S
-1	0.7 ± 0.2	1.7 ± 0.2	0.3 ± 0.1	0.4 ± 0.0	0.4 ± 0.0
2	1.0 ± 0.4	4.7 ± 0.8	2.0 ± 0.2	0.3 ± 0.0	3.5 ± 0.5
6	1.0 ± 0.5	1.8 ± 0.2	0.7 ± 0.1	0.3 ± 0.0	0.8 ± 0.2
9	0.9 ± 0.2	1.1 ± 0.1	0.5 ± 0.0	5.3 ± 0.1	0.6 ± 0.1
13	1.0 ± 0.7	2.3 ± 0.2	0.5 ± 0.1	0.9 ± 0.1	0.6 ± 0.1
16	0.5 ± 0.2	2.2 ± 0.2	0.4 ± 0.1	0.7 ± 0.1	0.6 ± 0.1
20	0.5 ± 0.0	2.6 ± 0.0	0.3 ± 0.0	0.6 ± 0.0	0.4 ± 0.0
23	0.5 ± 0.1	2.5 ± 0.1	0.3 ± 0.0	0.7 ± 0.0	0.5 ± 0.0
28	0.5 ± 0.1	2.4 ± 0.2	0.3 ± 0.0	0.7 ± 0.1	0.4 ± 0.0
31	0.7 ± 0.2	2.2 ± 0.2	0.5 ± 0.1	0.7 ± 0.1	0.4 ± 0.0
35	1.0 ± 0.4	2.5 ± 0.1	0.5 ± 0.1	0.7 ± 0.0	0.4 ± 0.0
38	1.2 ± 0.6	3.0 ± 0.3	0.6 ± 0.2	0.9 ± 0.1	0.4 ± 0.0
Contrast[x]					
Linear	NS	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS	NS

[z] Means are of four replications of an homogenous tissue sample removed from a plot 7.62 m long and 1.5 m wide.
[y] DAT=days after treatment. Experimental sampling occurred from June 19 to July 28, 2017.
[x] Significance for linear and quadratic orthogonal contracts. NS = Non-significant.

Table 4. Mean Value[z] and Standard Deviation for Leaf Tissue Micronutrient Content of Creeping Bentgrass (*Agrostis stolonifera*) in the Horticulture Treatment Plot (1x) at Mounier Golf Training Center at Weibring Golf Club, Normal, IL.

DAT[y]	Tissue Concentration ppm				
	B	Cu	Fe	Mn	Zn
-1	16.7 ± 1.8	14.5 ± 4.7	610.0 ± 113.2	52.1 ± 11.8	33.8 ± 2.7
2	23.2 ± 1.9	39.5 ± 28.6	946.9 ± 514.4	70.2 ± 20.3	20.1 ± 2.2
6	27.9 ± 1.9	14.2 ± 0.8	1053.0 ± 788.0	73.0 ± 34.6	24.8 ± 1.5
9	57.3 ± 9.8	25.2 ± 6.6	4960.3 ± 132.8	210.2 ± 18.1	286.6 ± 1.7
13	75.1 ± 6.9	17.6 ± 1.0	1227.8 ± 465.3	151.0 ± 35.1	58.5 ± 7.4
16	20.0 ± 0.5	16.3 ± 0.4	337.5 ± 115.6	120.9 ± 4.7	41.9 ± 2.0
20	24.9 ± 1.0	15.1 ± 0.1	395.8 ± 38.9	82.6 ± 2.0	32.0 ± 0.9
23	38.1 ± 1.9	18.5 ± 0.7	349.0 ± 53.9	84.1 ± 7.7	33.2 ± 1.7
28	25.2 ± 2.6	16.8 ± 1.7	386.8 ± 75.0	59.1 ± 12.0	29.0 ± 3.8
31	24.0 ± 1.5	19.8 ± 6.1	753.3 ± 243.2	69.2 ± 11.6	29.3 ± 1.4
35	28.0 ± 1.1	15.7 ± 0.7	957.3 ± 429.1	87.8 ± 25.0	30.6 ± 1.0
38	29.2 ± 1.9	20.9 ± 1.7	1041.3 ± 494.3	132.2 ± 10.3	25.8 ± 2.2
Contrast[x]					
Linear	NS	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS	NS

[z] Means are of four replications of an homogenous tissue sample removed from a plot 7.62 m long and 1.5 m wide.

[y] DAT=days after treatment. Experimental sampling occurred from June 19 to July 28, 2017.

[x] Significance for linear and quadratic orthogonal contracts. NS = Non-significant.

Table 5. Mean Value[z] and Standard Deviation for Leaf Tissue Macronutrient Content of Creeping Bentgrass (*Agrostis stolonifera*) in the Agronomic Treatment Plot (2x) at Mounier Golf Training Center at Weibring Golf Club, Normal, IL.

DAT[y]	% Tissue Concentration				
	Ca	K	Mg	P	S
-1	0.84 ± 0.14	1.91 ± 0.18	0.45 ± 0.06	0.51 ± 0.06	0.46 ± 0.06
2	0.65 ± 0.06	5.66 ± 0.75	2.23 ± 0.22	0.33 ± 0.04	4.05 ± 0.46
6	0.71 ± 0.05	2.28 ± 0.26	0.69 ± 0.06	0.4 ± 0.04	1.05 ± 0.11
9	0.63 ± 0.08	1.12 ± 0.02	0.47 ± 0.03	5.6 ± 0.34	0.66 ± 0.05
13	0.52 ± 0.03	2.35 ± 0.06	0.41 ± 0.01	1 ± 0.02	0.61 ± 0.03
16	0.39 ± 0.04	2.35 ± 0.19	0.35 ± 0.02	0.83 ± 0.08	0.62 ± 0.07
20	0.47 ± 0.05	2.82 ± 0.47	0.34 ± 0.04	0.73 ± 0.09	0.48 ± 0.07
23	0.52 ± 0.13	2.48 ± 0.1	0.33 ± 0.01	0.77 ± 0.04	0.49 ± 0.01
28	0.43 ± 0.04	2.45 ± 0.27	0.32 ± 0.02	0.76 ± 0.08	0.44 ± 0.04
31	0.73 ± 0.11	2.18 ± 0.08	0.44 ± 0.06	0.76 ± 0.02	0.43 ± 0.01
35	0.72 ± 0.43	2.36 ± 0.24	0.41 ± 0.13	0.69 ± 0.07	0.36 ± 0.03
38	0.73 ± 0.06	3.44 ± 0.17	0.47 ± 0.03	1.06 ± 0.05	0.32 ± 0.19
Contrast[x]					
Linear	NS	NS	NS	NS	NS
Quadratic	P = 0.04	NS	NS	NS	NS

[z] Means are of four replications of an homogenous tissue sample removed from a plot 7.62 m long and 1.5 m wide.
[y] DAT=days after treatment. Experimental sampling occurred from June 19 to July 28, 2017.
[x] Significance for linear and quadratic orthogonal contracts. NS = Non-significant.

Table 6. Mean Value[z] and Standard Deviation for Leaf Tissue Micronutrient Content of Creeping Bentgrass (*Agrostis stolonifera*) in the Agronomic Treatment Plot (2x) at Mounier Golf Training Center at Weibring Golf Club, Normal, IL.

DAT[y]	Tissue Concentration ppm				
	B	Cu	Fe	Mn	Zn
-1	19.6 ± 3.61	15.4 ± 3.2	777.1 ± 139.4	54.9 ± 8.1	39.4 ± 6.06
2	25.2 ± 3.66	37.3 ± 16.8	1112 ± 1091	47.7 ± 5.11	22.3 ± 2.14
6	34.1 ± 3.19	14 ± 0.42	732 ± 140.9	56.1 ± 2.24	29.8 ± 2.75
9	55.6 ± 5.38	26.2 ± 4.53	5214 ± 477.8	208 ± 23.3	262 ± 28.2
13	82.9 ± 0.92	16.5 ± 1.01	1090 ± 78.05	137 ± 12.3	67.1 ± 11
16	20.8 ± 2.41	18.4 ± 1.73	328.5 ± 49.56	132 ± 8.21	43.4 ± 5.7
20	26 ± 3.53	16.6 ± 2.24	405 ± 34.41	90.4 ± 12	34.5 ± 4.37
23	36.4 ± 2.01	18.7 ± 1.26	318.3 ± 28.48	84.7 ± 9.6	33 ± 0.42
28	24.1 ± 1.85	17.5 ± 2.11	268 ± 55.41	56.1 ± 4.37	31.3 ± 3.65
31	22.2 ± 0.75	16.7 ± 0.53	612.8 ± 150	69.5 ± 14.2	28.1 ± 0.57
35	25.6 ± 3.02	14.3 ± 1.84	475 ± 562.2	65.4 ± 30.6	29.1 ± 2.73
38	32.2 ± 0.84	23.8 ± 1	660.5 ± 117	131 ± 3.43	30.7 ± 1.08
Contrast[x]					
Linear	NS	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS	NS

[z] Means are of four replications of an homogenous tissue sample removed from a plot 7.62 m long and 1.5 m wide.
[y] DAT=days after treatment. Experimental sampling occurred from June 19 to July 28, 2017.
[x] Significance for linear and quadratic orthogonal contracts. NS = Non-significant.

Table 7. Mean Value[z] and Standard Deviation for Leaf Tissue Macronutrient Content of Creeping Bentgrass (*Agrostis stolonifera*) in the Control Plot at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL.

DAT[y]	% Tissue Concentration				
	Ca	K	Mg	P	S
-1	0.77 ± 0.1	1.16 ± 0.06	0.43 ± 0.05	0.31 ± 0.01	0.25 ± 0.02
2	0.75 ± 0.1	1.29 ± 0.19	0.43 ± 0.05	0.34 ± 0.04	0.28 ± 0.06
6	0.63 ± 0.0	1.46 ± 0.14	0.34 ± 0.03	0.34 ± 0.03	0.26 ± 0.02
9	0.98 ± 0.3	1.06 ± 0.24	0.52 ± 0.11	0.26 ± 0.03	0.62 ± 0.92
13	0.76 ± 0.1	1 ± 0.14	0.35 ± 0.14	0.3 ± 0.04	0.2 ± 0.03
16	1.11 ± 0.2	1.28 ± 0.15	0.56 ± 0.06	0.42 ± 0.05	0.25 ± 0.04
20	0.6 ± 0.1	1.24 ± 0.18	0.38 ± 0.05	0.36 ± 0.04	0.19 ± 0.11
23	0.80 ± 0.0	1.98 ± 0.34	0.38 ± 0.23	0.56 ± 0.02	0.35 ± 0.01
28	0.66 ± 0.0	2.16 ± 0.08	0.4 ± 0.02	0.54 ± 0.02	0.34 ± 0.02
31	0.64 ± 0.1	1.5 ± 0.08	0.39 ± 0.02	0.55 ± 0.03	0.35 ± 0.02
35	0.56 ± 0.1	1.75 ± 0.3	0.36 ± 0.02	0.44 ± 0.01	0.33 ± 0.03
38	0.55 ± 0.0	1.5 ± 0.04	0.34 ± 0.01	0.53 ± 0.01	0.33 ± 0.02
Contrast[x]					
Linear	NS	P = 0.05	NS	P = 0.00	NS
Quadratic	NS	NS	NS	NS	NS

[z] Means are of four replications of an homogenous tissue sample removed from a plot 7.62 m long and 1.5 m wide.
[y] DAT=days after treatment. Experimental sampling occurred from June 19 to July 28, 2017.
[x] Significance for linear and quadratic orthogonal contracts. NS = Non-significant.

Table 8. Mean Value[z] and Standard Deviation for Leaf Tissue Micronutrient Content of Creeping Bentgrass (*Agrostis stolonifera*) in the Control Plot at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL.

DAT[y]	Tissue Concentration ppm				
	B	Cu	Fe	Mn	Zn
-1	17.95 ± 1.1	12.38 ± 0.88	1077 ± 273.3	47.03 ± 8.76	23.28 ± 1.396
2	17.63 ± 3.2	9.025 ± 2.164	578.4 ± 180.2	42.42 ± 5.106	27.12 ± 4.317
6	26.4 ± 2.2	8.75 ± 0.755	770 ± 220.5	43.25 ± 4.39	25.08 ± 1.164
9	16.13 ± 1.3	9.025 ± 1.493	1499 ± 116.3	87.63 ± 15.54	21.1 ± 2.061
13	17.08 ± 0.8	9.625 ± 0.427	1098 ± 277.6	52.9 ± 3.367	26.38 ± 0.866
16	25.5 ± 1.6	11.53 ± 1.204	1243 ± 457	117.6 ± 11.89	28.05 ± 2.797
20	11.18 ± 1.5	10.08 ± 0.995	696.5 ± 115	55.48 ± 5.235	24.98 ± 1.864
23	29.03 ± 4.7	13.18 ± 2.019	722.3 ± 166.7	89.2 ± 3.284	445.1 ± 88.08
28	30.13 ± 1.2	14.23 ± 0.665	326.3 ± 108.1	52.25 ± 3.931	154.5 ± 6.418
31	26.23 ± 0.8	11.85 ± 0.342	528 ± 406.4	46.45 ± 7.116	81.13 ± 3.052
35	27.08 ± 6.2	13.25 ± 0.532	229.5 ± 114.8	44.13 ± 1.871	91.55 ± 34.47
38	15.4 ± 0.6	14.1 ± 0.497	229.8 ± 94.07	36.7 ± 0.966	54.28 ± 2.35
Contrast[x]					
Linear	NS	P = 0.01	P = 0.01	NS	NS
Quadratic	NS	NS	P = 0.08	P = 0.04	NS

[z] Means are of four replications of an homogenous tissue sample removed from a plot 7.62 m long and 1.5 m wide.
[y] DAT=days after treatment. Experimental sampling occurred from June 19 to July 28, 2017.
[x] Significance for linear and quadratic orthogonal contracts. NS = Non-significant.

Table 9. Mean Value[z] and Standard Deviation for Leaf Tissue Macronutrient Content of Creeping Bentgrass (*Agrostis stolonifera*) in the Horticulture Treatment Plot (1x) at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL.

DAT[y]	% Tissue Concentration				
	Ca	K	Mg	P	S
-1	0.79 ± 0.085	1.265 ± 0.056	0.425 ± 0.05	8.745 ± 16.84	0.258 ± 0.021
2	0.678 ± 0.074	1.26 ± 0.069	0.375 ± 0.05	0.333 ± 0.024	0.255 ± 0.017
6	0.668 ± 0.102	1.433 ± 0.242	0.35 ± 0.041	0.34 ± 0.057	0.245 ± 0.049
9	1.783 ± 0.417	1.31 ± 0.282	0.878 ± 0.184	0.303 ± 0.061	0.213 ± 0.05
13	1.213 ± 0.296	1.1 ± 0.115	0.63 ± 0.017	0.325 ± 0.035	0.22 ± 0.032
16	1.02 ± 0.104	1.375 ± 0.096	0.57 ± 0.102	0.415 ± 0.062	0.243 ± 0.035
20	0.783 ± 0.151	1.503 ± 0.114	0.478 ± 0.07	0.403 ± 0.035	0.263 ± 0.03
23	0.905 ± 0.185	1.873 ± 0.092	0.505 ± 0.079	0.638 ± 0.05	0.373 ± 0.034
28	0.638 ± 0.068	2.148 ± 0.066	0.39 ± 0.026	0.543 ± 0.022	0.359 ± 0.012
31	0.688 ± 0.15	1.45 ± 0.129	0.433 ± 0.078	0.475 ± 0.031	0.305 ± 0.026
35	0.635 ± 0.062	1.568 ± 0.068	0.383 ± 0.017	0.503 ± 0.019	0.313 ± 0.019
38	0.53 ± 0.029	1.495 ± 0.061	0.34 ± 0.008	0.51 ± 0.022	0.34 ± 0.014
Contrast[x]					
Linear	NS	P = 0.07	NS	NS	P = 0.01
Quadratic	NS	NS	P = 0.08	P = 0.04	NS

[z] Means are of four replications of an homogenous tissue sample removed from a plot 7.62 m long and 1.5 m wide.
[y] DAT=days after treatment. Experimental sampling occurred from June 19 to July 28, 2017.
[x] Significance for linear and quadratic orthogonal contracts. NS = Non-significant.

Table 10. Mean Value[z] and Standard Deviation for Leaf Tissue Micronutrient Content of Creeping Bentgrass (*Agrostis stolonifera*) in the Horticulture Treatment Plot (1x) at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL.

DAT[y]	Tissue Concentration ppm				
	B	Cu	Fe	Mn	Zn
-1	19.53 ± 1.333	10.8 ± 4.414	395.7 ± 81.78	40.77 ± 4.414	23.21 ± 1.943
2	15.6 ± 0.632	8.25 ± 0.806	397.2 ± 93.24	40.81 ± 2.557	24.97 ± 1.174
6	26.33 ± 2.54	7.875 ± 1.884	447.5 ± 118.7	42.95 ± 5.422	23.25 ± 3.042
9	20.33 ± 2.066	10.68 ± 1.702	1897 ± 377.9	121.5 ± 3.553	26.83 ± 0.738
13	19.75 ± 1.895	9.175 ± 0.714	1195 ± 376.5	66.8 ± 14.35	26.48 ± 3.381
16	24.1 ± 3.483	12 ± 1.052	903.8 ± 172.3	137.5 ± 8.7	22.93 ± 3.326
20	10.55 ± 0.617	10.95 ± 0.755	557.3 ± 165.4	64.25 ± 9.385	25.38 ± 0.746
23	36.65 ± 1.515	12.55 ± 0.332	677.5 ± 248.5	94.18 ± 12.77	510.2 ± 14.27
28	32.13 ± 3.214	14.58 ± 1.132	239.5 ± 80.46	49.23 ± 6.025	147.3 ± 12.89
31	22.2 ± 1.095	10.6 ± 0.825	402 ± 110.5	39.08 ± 2.29	60.2 ± 3.349
35	23.08 ± 1.187	14.08 ± 0.714	286.8 ± 37.21	42.63 ± 2.953	55.25 ± 1.287
38	17.13 ± 0.395	14.18 ± 0.85	153.8 ± 17.21	34.03 ± 3.583	47.55 ± 2.412
Contrast[x]					
Linear	NS	P = 0.00	NS	NS	NS
Quadratic	NS	NS	P = 0.06	P = 0.02	NS

[z] Means are of four replications of an homogenous tissue sample removed from a plot 7.62 m long and 1.5 m wide.
[y] DAT=days after treatment. Experimental sampling occurred from June 19 to July 28, 2017.
[x] Significance for linear and quadratic orthogonal contracts. NS = Non-significant.

Table 11. Mean Value[z] and Standard Deviation for Leaf Tissue Macronutrient Content of Creeping Bentgrass (*Agrostis stolonifera*) in the Agronomic Treatment Plot (2x) at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL.

DAT[y]	% Tissue Concentration				
	Ca	K	Mg	P	S
-1	0.755 ± 0.029	1.283 ± 0.057	0.4 ± 0	0.315 ± 0.006	0.285 ± 0.013
2	0.728 ± 0.089	1.605 ± 0.266	0.375 ± 0.05	0.39 ± 0.048	0.335 ± 0.052
6	0.565 ± 0.07	1.578 ± 0.127	0.32 ± 0.032	0.315 ± 0.031	0.28 ± 0.042
9	1.02 ± 0.271	1.483 ± 0.159	0.53 ± 0.122	0.338 ± 0.042	0.265 ± 0.045
13	0.748 ± 0.152	1.25 ± 0.1	0.41 ± 0.047	0.343 ± 0.032	0.265 ± 0.034
16	0.71 ± 0.153	1.4 ± 0.082	0.433 ± 0.057	0.428 ± 0.061	0.285 ± 0.041
20	0.57 ± 0.086	1.555 ± 0.114	0.38 ± 0.024	0.43 ± 0.029	0.308 ± 0.032
23	0.73 ± 0.098	2.06 ± 0.032	0.448 ± 0.042	0.7 ± 0.05	0.445 ± 0.024
28	0.628 ± 0.123	1.88 ± 0.158	0.315 ± 0.064	0.348 ± 0.165	0.238 ± 0.124
31	0.645 ± 0.051	1.6 ± 0.082	0.415 ± 0.021	0.488 ± 0.046	0.355 ± 0.019
35	0.53 ± 0.051	1.628 ± 0.105	0.355 ± 0.024	0.493 ± 0.033	0.338 ± 0.026
38	0.483 ± 0.013	1.415 ± 0.102	0.31 ± 0.018	0.47 ± 0.029	0.325 ± 0.026
Contrast[x]					
Linear	P = 0.05	NS	NS	P = 0.05	NS
Quadratic	NS	NS	NS	NS	NS

[z] Means are of four replications of an homogenous tissue sample removed from a plot 7.62 m long and 1.5 m wide.
[y] DAT=days after treatment. Experimental sampling occurred from June 19 to July 28, 2017.
[x] Significance for linear and quadratic orthogonal contracts. NS = Non-significant.

Table 12. Mean Value[z] and Standard Deviation for Leaf Tissue Micronutrient Content of Creeping Bentgrass (*Agrostis stolonifera*) in the Agronomic Treatment Plot (2x) at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL.

DAT[y]	Tissue Concentration ppm				
	B	Cu	Fe	Mn	Zn
-1	19.2 ± 2.893	11.18 ± 3.568	355.1 ± 92.35	41.26 ± 2.836	23.41 ± 0.598
2	17.63 ± 2.895	12.7 ± 3.218	334.7 ± 40.27	50.19 ± 7.864	31.43 ± 3.996
6	27.05 ± 4.173	8.15 ± 1.156	311.8 ± 143.7	36.15 ± 7.117	23.13 ± 2.226
9	19.53 ± 2.105	12.08 ± 1.274	986.8 ± 357.5	108.3 ± 10.11	24.69 ± 2.199
13	18.55 ± 0.998	9.15 ± 0.603	615.3 ± 192.6	49.53 ± 5.278	25.58 ± 1.144
16	29.35 ± 5.546	13.2 ± 1.219	708.5 ± 229	118 ± 9.288	23.8 ± 3.424
20	11.45 ± 1.012	11.75 ± 0.819	379.5 ± 78.67	54.7 ± 3.303	27.08 ± 2.019
23	43.2 ± 3.176	14.03 ± 0.32	483.3 ± 91.6	92.53 ± 6.904	614.2 ± 69.42
28	20.45 ± 9.56	11.75 ± 2.768	140.5 ± 34.32	31.68 ± 12.04	79.25 ± 65.69
31	27.85 ± 2.014	13.28 ± 1.431	388.3 ± 45.75	42.83 ± 2.406	63.65 ± 9.479
35	25.13 ± 2.933	14.73 ± 0.768	219.8 ± 32.19	40.93 ± 2.49	55.65 ± 5.798
38	18.2 ± 1.936	13.98 ± 1.502	192 ± 30.3	35.28 ± 1.841	46.05 ± 1.733
Contrast[x]					
Linear	NS	P = 0.03	NS	NS	NS
Quadratic	NS	NS	P = 0.07	P = 0.07	NS

[z] Means are of four replications of an homogenous tissue sample removed from a plot 7.62 m long and 1.5 m wide.
[y] DAT=days after treatment. Experimental sampling occurred from June 19 to July 28, 2017.
[x] Significance for linear and quadratic orthogonal contracts. NS = Non-significant.

CHAPTER IV: CONCLUSIONS AND RECOMMENDATIONS

The goal of this experiment was to determine if foliar applied titanium affected the growth and quality of creeping bentgrass at two locations in Central Illinois using two different rates. Based on the results from the experiment, it can be reasoned that foliar titanium affected the growth and quality of creeping bentgrass at both locations. However, these effects were site and rate specific, causing nutrient concentrations to increase or decrease which makes it difficult to make a single, universal recommendation for creeping bentgrass. Individual rates would be more beneficial for each individual location at this time, as well as applying Tytanit® at the same time as a fertilizer application, which was proven to make the fertilizer application more efficient in this study.

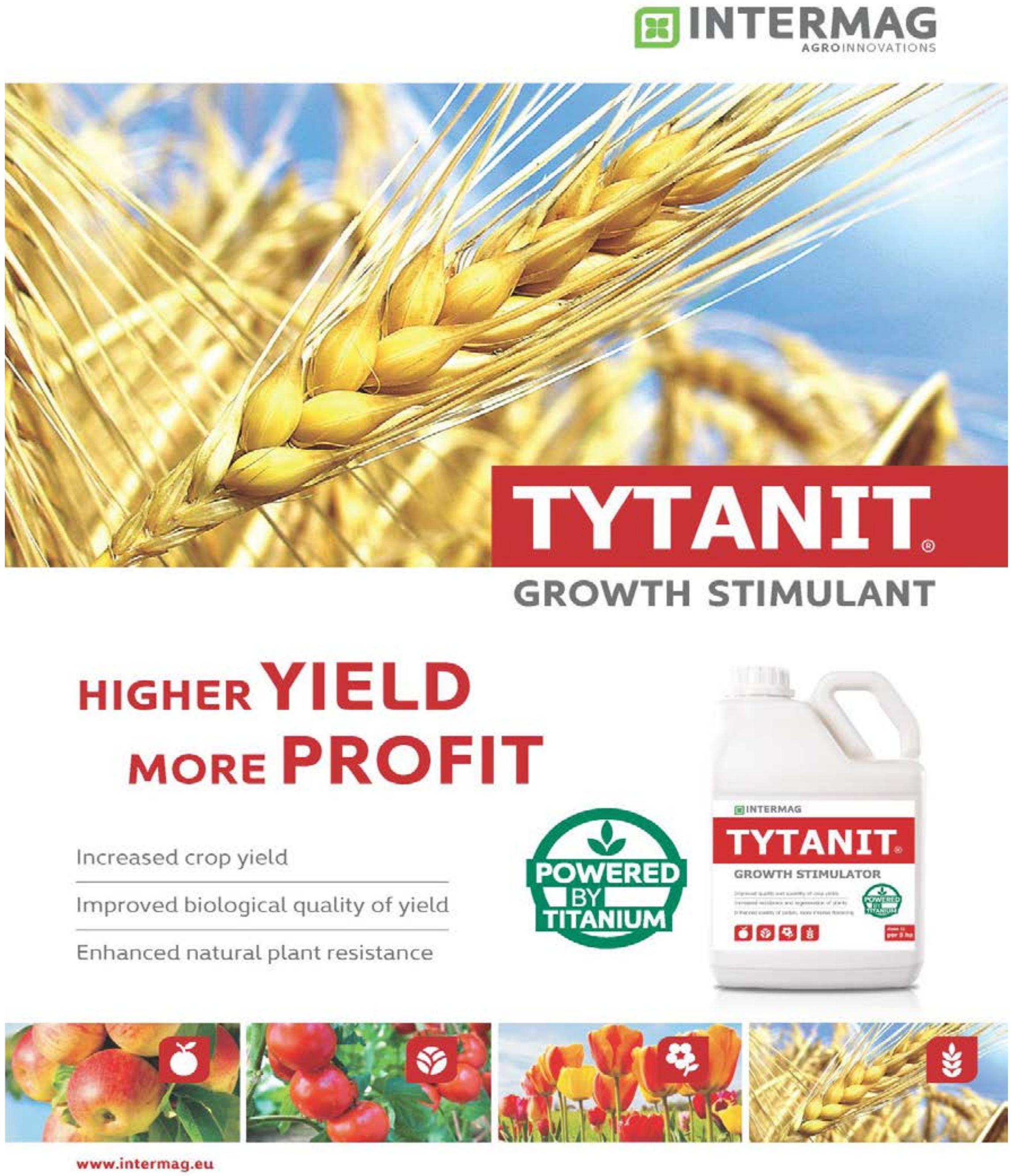
The delayed response at Lauritsen/Wohler's Outdoor Golf Practice Facility in nutrient response to the Ti application is hard to explain. Since it is a newer putting green, it is possible the Tytanit® stayed in the upper soil surface where the peat is. Peat typically deteriorates in a few years following putting green construction, but this green is only a few years old. Other than that, there was adequate moisture at the time so it is possible a lack of rainfall or irrigation following the application left the Tytanit® in the upper soil profile.

Nitrogen uptake was not tested with the soil and tissue samples. One reason for this is the extra cost per sample to test for nitrogen at the lab. The other reason is each golf course superintendent has his or her own nitrogen application plan in terms of "spoon-feeding" the creeping bentgrass, meaning it would have been difficult to track each superintendent's nitrogen plan with the Ti application. Rainfall was not tracked either because if there was a shortage of water, the superintendents irrigated the putting green, so that also would have difficult to track and not really feasible.

Tytanit® has the potential to benefit creeping bentgrass in a sandy profile on golf courses in Central Illinois. However, because of the limited research previously done with applying Tytanit® on turf, more research could be done to gain a better understanding of the exact impact Tytanit® has on turf, specifically creeping bentgrass in a more consistent manner. Our research indicated it does make sense to apply Tytanit® with your fertilizer application either before, with, or immediately after for more efficient fertilizer usage and nutrient uptake. Other than that, it'd be hard for us to recommend a single, universal rate for creeping bentgrass on sandy profiles at this time.

Results from this 2017 research study were presented to the Central Illinois Golf Course Superintendents Association of America (CI-GCSAA) at their regional meetings in December 2017, developed into a popular press article for the regional and state GCSAA group newsletters, and submitted for publication to a professional turfgrass journal. A final project report will be delivered to the CI-CGSAA by June 30, 2018.

APPENDIX A: TYTANIT® PRODUCT LABEL



APPENDIX B: SOIL TESTING RESULTS

Table B-1. Soil Statistics at Mounier Golf Training Center at Weibring Golf Club, Normal, IL, June 19, 2017.

Sample #	pH water	pH buffer	OM%	CEC meq/100g
Control	7.0	7.0	1.0	17.0
Control	7.0	7.0	0.6	16.4
Control	8.0	7.0	0.5	17.1
Control	7.0	7.0	0.6	17.1
1x	8.0	7.0	1.1	17.9
1x	8.0	7.0	0.4	17.4
1x	7.0	7.0	0.4	15.2
1x	7.8.0	7.0	0.8	17.3
2x	8.1	7.0	0.6	16.4
2x	8.1	7.0	1.2	18.1
2x	8.0	7.0	0.4	14.8
2x	8.0	7.0	0.6	19.2
Averages	7.7	7.0	0.68	17.0

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

Table B-2. Soil Statistics at Mounier Golf Training Center at Weibring Golf Club, Normal, IL, July 6, 2017.

Sample #	pH water	pH buffer	OM%	CEC meq/100g
Control	7.1	7.0	1.9	13.6
Control	7.5	7.0	1.5	18.3
Control	7.3	7.0	1.6	13.7
Control	7.4	7.0	1.5	19.1
1x	7.5	7.0	1.1	16.7
1x	7.6	7.0	0.9	21.3
1x	7.7	7.0	1.0	17.6
1x	7.7	7.0	1.6	21.8
2x	7.7	7.0	2.0	19.1
2x	7.5	7.0	0.9	18.3
2x	7.6	7.0	1.1	18.1
2x	7.4	7.0	1.0	20.0
Averages	7.5	7.0	1.3	18.1

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

Table B-3. Soil Statistics at Mounier Golf Training Center at Weibring Golf Club, Normal, IL, July 20, 2017.

Sample #	pH water	pH buffer	OM%	CEC meq/100g
Control	7.7	7.0	0.7	26.3
Control	8.0	7.0	0.6	21.5
Control	7.7	7.0	0.5	20.8
Control	8.0	7.0	0.6	18.9
1x	7.9	7.0	0.4	25.1
1x	8.4	7.0	0.5	17.9
1x	8.2	7.0	0.7	23.4
1x	8.3	7.0	0.7	26.6
2x	8.3	7.0	0.6	28.9
2x	8.5	7.0	0.5	16.5
2x	8.3	7.0	0.5	19.4
2x	8.6	7.0	0.4	17.3
Averages	8.15	7.0	0.55	21.8

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

Table B-4. Soil Statistics at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL, June 20, 2017.

Sample #	pH water	pH buffer	OM%	CEC meq/100g
Control	8.4	7.0	0.4	16.7
Control	8.3	7.0	0.4	14.1
Control	8.4	7.0	0.5	18.5
Control	8.2	7.0	0.6	21.3
1x	8.5	7.0	0.4	15.6
1x	8.3	7.0	0.4	24.1
1x	8.4	7.0	0.5	16.8
1x	8.5	7.0	0.5	18.7
2x	8.7	7.0	0.6	19.5
2x	8.5	7.0	0.7	16.9
2x	8.5	7.0	0.5	20.6
2x	8.6	7.0	0.4	25.7
Averages	8.4	7.0	0.5	19.0

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

Table B-5. Soil Statistics at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL, July 7, 2017.

Sample #	pH water	pH buffer	OM%	CEC meq/100g
Control	7.7	7.0	1.0	26.2
Control	7.8	7.0	0.6	19.8
Control	8.0	7.0	0.5	23.4
Control	8.1	7.0	0.6	19.2
1x	8.2	7.0	1.1	26.1
1x	8.2	7.0	0.4	18.5
1x	7.9	7.0	0.4	16.3
1x	7.8	7.0	0.8	18.7
2x	8.2	7.0	0.6	25.6
2x	8.0	7.0	1.2	20.4
2x	7.9	7.0	0.4	20.2
2x	8.5	7.0	0.6	19.7
Averages	8.0	7.0	0.7	21.2

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

Table B-6. Soil Statistics at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, July 21, 2017.

Sample #	pH water	pH buffer	OM%	CEC meq/100g
Control	8.1	7.0	1.1	17.3
Control	8.0	7.0	1.5	18.2
Control	8.1	7.0	1.4	16.6
Control	8.1	7.0	1.5	17.1
1x	8.1	7.0	1.1	20.3
1x	8.3	7.0	1.1	19.2
1x	8.2	7.0	1.5	18.1
1x	8.1	7.0	1.4	17.9
2x	8.2	7.0	1.1	15.4
2x	8.4	7.0	1.7	16.7
2x	8.6	7.0	1.4	15.8
2x	8.4	7.0	1.6	13.9
Averages	8.2	7.0	1.4	17.2

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

APPENDIX C: TISSUE TESTING RESULTS

Table C-1. Nutrient Concentration in Plant Tissue at Mounier Golf Training Center at Weibring Golf Club, Normal, IL, June 19, 2017.

Lab ID	Boron PPM	Calcium %	Copper PPM	Iron PPM	Potassium %	Magnesium %	Manganese PPM	Sodium %	Phosphorus %	Sulfur %	Zinc PPM
Control	20.3	1.04	10.6	2108.	1.40	.5	81.71	.025	.37	.33	41.85
Control	21.7	.98	12.3	1398	1.66	.4	68.55	.036	.43	.40	39.42
Control	18.5	.65	10.6	1207	1.63	.3	133.53	.028	.41	.37	32.43
Control	18.1	.70	12.3	800.0	1.79	.3	60.08	.019	.46	.43	37.37
1x	16.1	.59	14.2	486.5	1.94	.3	45.22	.022	.49	.42	37.77
1x	14.6	.63	10.7	585.0	1.51	.3	41.77	.004	.39	.35	31.81
1x	17.0	.78	21.2	608.4	1.68	.3	53.29	.007	.43	.37	32.52
1x	18.9	.96	11.7	760.1	1.64	.4	68.26	.037	.42	.37	33.09
2x	16.9	.71	13.1	651.7	1.91	.4	47.57	.0258	.47	.43	35.59
2x	19.4	.97	14.7	890.1	1.83	.5	58.61	.056	.50	.43	37.22
2x	17.2	.73	13.7	661.4	1.75	.4	48.9	.052	.47	.42	36.47
2x	24.7	.95	20.1	905.2	2.16	.5	64.56	.064	.60	.54	48.48

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

Table C-2. Nutrient Concentration in Plant Tissue at Mounier Golf Training Center at Weibring Golf Club, Normal, IL, June 22, 2017.

Lab ID	Boron PPM	Calcium %	Copper PPM	Iron PPM	Potassium %	Magnesium %	Manganese PPM	Sodium %	Phosphorus %	Sulfur %	Zinc PPM
Control	24.9	1.00	8.1	1122	3.66	1.6	59.36	.077	.33	2.56	24.45
Control	24.4	1.00	6.2	855.3	5.42	2.2	57.95	.075	.27	3.67	18.26
Control	22.6	.78	7.1	729.0	4.44	1.9	60.76	.079	.27	3.26	17.87
Control	22.7	.91	22.5	812.3	4.58	1.9	61.95	.066	.27	3.43	18.72
1x	21.1	.62	24.7	448.5	4.59	1.9	50.75	.076	.30	3.65	20.45
1x	22.8	.74	21.2	666.0	5.91	2.3	58.62	.055	.24	4.08	16.91
1x	23.3	1.23	82.0	1051.2	4.48	2.0	74.61	.069	.31	3.25	21.86
1x	25.6	1.53	30.1	1622	3.93	1.9	96.79	.067	.30	2.85	21.05
2x	30.2	.62	45.4	2741	4.84	2.0	53.12	.062	.31	3.74	20.73
2x	21.6	.65	56.0	515.9	6.60	2.5	45.54	.060	.29	4.70	20.16
2x	23.7	.60	29.4	474.7	5.87	2.3	41.71	.072	.35	4.02	23.97
2x	25.1	.74	18.2	716.1	5.34	2.1	50.59	.072	.37	3.72	24.27

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

Table C-3. Nutrient Concentration in Plant Tissue at Mounier Golf Training Center at Weibring Golf Club, Normal, IL, June 26, 2017.

Lab ID	Boron PPM	Calcium %	Copper PPM	Iron PPM	Potassium %	Magnesium %	Manganese PPM	Sodium %	Phosphorus %	Sulfur %	Zinc PPM
Control	26.4	0.70	12.4	1218	1.72	0.62	59.0	0.06	0.30	0.88	30.9
Control	27.8	1.00	11.4	1433	1.61	0.65	79.6	0.05	0.25	0.78	21.3
Control	34.9	0.93	13.9	1315	1.85	0.78	88.5	0.06	0.31	0.84	26.7
Control	37.9	0.88	16.3	919	2.24	0.71	66.2	0.06	0.41	1.02	30.2
1x	29.8	0.81	15.0	575	2.06	0.67	53.2	0.05	0.34	1.00	26.6
1x	29.0	0.64	14.6	731	1.96	0.66	56.8	0.05	0.33	1.01	25.5
1x	25.4	0.84	13.4	675	1.77	0.56	57.0	0.05	0.30	0.76	23.4
1x	27.4	1.82	13.7	2231	1.50	0.8	124.8	0.04	0.25	0.58	23.8
2x	29.4	0.75	14.4	766	1.93	0.61	56.5	0.05	0.34	0.88	25.8
2x	34.88	0.70	13.4	847	2.29	0.74	57.7	0.05	0.39	1.12	30.1
2x	36.40	0.73	14.1	788	2.35	0.72	57.3	0.57	0.42	1.10	31.9
2x	35.72	0.64	13.92	527	2.54	0.67	52.8	0.06	0.43	1.10	31.3

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

Table C-4. Nutrient Concentration in Plant Tissue at Mounier Golf Training Center at Weibring Golf Club, Normal, IL, June 29, 2017.

Lab ID	Boron PPM	Calcium %	Copper PPM	Iron PPM	Potassium %	Magnesium %	Manganese PPM	Sodium %	Phosphorus %	Sulfur %	Zinc PPM
Control	43.2	1.74	27.2	4235	1.20	0.87	174.0	0.070	3.55	0.51	122.2
Control	63.0	1.60	46.3	5078	1.06	0.71	220.7	0.079	4.76	0.54	192.1
Control	73.3	0.98	28.9	5665	1.07	0.51	208.1	0.08	5.68	0.63	239.8
Control	56.0	0.88	26.5	5173	1.16	0.50	210.8	0.085	5.68	0.67	286.6
1x	71.9	0.71	34.3	4827	1.18	0.49	236.0	0.094	5.41	0.70	256.1
1x	52.7	0.67	20.8	4902	1.14	0.46	193.6	0.087	5.30	0.65	245.1
1x	52.9	1.06	25.7	5138	1.05	0.54	207.0	0.093	5.26	0.58	441.1
1x	51.5	0.97	20.0	4974	1.20	0.47	204.3	0.094	5.30	0.62	204.0
2x	53.6	0.72	32.9	5196	1.10	0.47	229.3	0.09	5.46	0.66	244.5
2x	63.6	0.61	25.1	5881	1.12	0.46	226.2	0.10	6.08	0.73	303.3
2x	52.9	0.67	23.1	4770	1.12	0.50	184.2	0.08	5.31	0.64	244.0
2x	52.2	0.53	23.8	5008	1.14	0.43	191.5	0.09	5.53	0.62	255.3

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

Table C-5. Nutrient Concentration in Plant Tissue at Mounier Golf Training Center at Weibring Golf Club, Normal, IL, July 3, 2017.

Lab ID	Boron PPM	Calcium %	Copper PPM	Iron PPM	Potassium %	Magnesium %	Manganese PPM	Sodium %	Phosphorus %	Sulfur %	Zinc PPM
Control	59.1	1.25	14.4	2411	2.0	0.58	156.1	0.050	0.81	0.52	48.1
Control	67.9	1.02	14.0	1471	2.2	0.54	274.6	0.046	0.85	0.54	45.4
Control	82.1	0.63	16.1	1211	2.3	0.42	152.0	0.049	1.02	0.62	66.2
Control	81.8	0.51	17.1	1059	2.3	0.40	142.9	0.046	0.97	0.60	75.9
1x	83.0	0.49	17.7	921	2.6	0.43	159.7	0.061	1.04	0.74	68.4
1x	66.5	0.63	16.1	964	2.1	0.44	118.2	0.046	0.85	0.58	52.0
1x	73.5	0.95	18.4	1111	2.2	0.55	129.6	0.051	0.92	0.59	53.6
1x	77.2	1.97	18.2	1915	2.3	0.68	196.6	0.056	0.97	0.60	59.9
2x	82.6	0.51	17.4	1150	2.4	0.41	137.3	0.049	1.03	0.63	64.1
2x	82.8	0.51	15.7	1149	2.3	0.42	153.5	0.048	0.97	0.60	83.3
2x	84.1	0.49	17.3	985	2.4	0.41	124.8	0.050	1.00	0.64	61.7
2x	81.9	0.57	15.5	1077	2.3	0.41	131.5	0.051	1.00	0.57	59.3

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

Table C-6. Nutrient Concentration in Plant Tissue at Mounier Golf Training Center at Weibring Golf Club, Normal, IL, July 6, 2017.

Lab ID	Boron PPM	Calcium %	Copper PPM	Iron PPM	Potassium %	Magnesium %	Manganese PPM	Sodium %	Phosphorus %	Sulfur %	Zinc PPM
Control	22.8	1.60	13.3	2142	1.8	0.83	150.0	0.047	0.62	0.48	33.8
Control	20.0	1.09	13.4	1837	1.7	0.58	142.6	0.045	0.58	0.45	50.0
Control	18.5	0.86	15.2	991	2.1	0.48	152.1	0.049	0.68	0.51	35.1
Control	18.4	0.67	16.2	611	2.2	0.39	154.4	0.050	0.74	0.55	39.7
1x	19.4	0.40	16.2	261	2.4	0.36	126.9	0.053	0.80	0.63	42.1
1x	20.4	0.32	16.8	243	2.1	0.31	118.6	0.044	0.76	0.60	42.6
1x	20.5	0.41	15.9	350	2.2	0.33	116.0	0.044	0.74	0.57	39.2
1x	19.7	0.77	16.4	496	2.0	0.43	122.2	0.053	0.65	0.50	43.8
2x	18.8	0.44	17.2	371	2.2	0.34	126.8	0.044	0.75	0.56	36.3
2x	20.1	0.36	17.3	308	2.2	0.33	126.2	0.045	0.79	0.59	42.4
2x	24.33	0.40	20.9	367	2.6	0.37	143.9	0.051	0.94	0.71	50.0
2x	20.1	0.37	18.2	268	2.4	0.34	131.9	0.050	0.82	0.60	45.0

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

Table C-7. Nutrient Concentration in Plant Tissue at Mounier Golf Training Center at Weibring Golf Club, Normal, IL, July 10, 2017.

Lab ID	Boron PPM	Calcium %	Copper PPM	Iron PPM	Potassium %	Magnesium %	Manganese PPM	Sodium %	Phosphorus %	Sulfur %	Zinc PPM
Control	19.6	1.44	9.5	1590	1.57	0.67	107.9	0.045	0.40	0.28	21.9
Control	22.9	0.65	12.7	806	2.24	0.38	89.8	0.056	0.55	0.37	26.7
Control	25.6	0.50	15.2	578	2.54	0.35	91.6	0.061	0.66	0.44	30.9
Control	25.7	0.47	15.5	364	2.67	0.33	87.5	0.062	0.68	0.45	30.7
1x	23.9	0.50	15.2	426	2.58	0.34	83.8	0.059	0.65	0.43	32.0
1x	24.9	0.44	15.2	377	2.55	0.32	82.4	0.055	0.66	0.43	33.3
1x	24.6	0.55	15.0	430	2.60	0.33	84.3	0.059	0.66	0.43	31.2
1x	26.2	0.50	14.9	350	2.52	0.31	79.8	0.071	0.62	0.42	31.4
2x	23.5	0.44	15.2	445	2.50	0.31	80.9	0.058	0.67	0.43	31.1
2x	22.5	0.41	14.1	369	2.34	0.29	79.3	0.055	0.64	0.40	30.4
2x	28.3	0.50	18.5	421	3.21	0.38	98.6	0.073	0.80	0.53	38.3
2x	29.7	0.53	18.4	385	3.24	0.36	102.7	0.079	0.82	0.54	38.3

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

Table C-8. Nutrient Concentration in Plant Tissue at Mounier Golf Training Center at Weibring Golf Club, Normal, IL, July 14, 2017.

Lab ID	Boron PPM	Calcium %	Copper PPM	Iron PPM	Potassium %	Magnesium %	Manganese PPM	Sodium %	Phosphorus %	Sulfur %	Zinc PPM
Control	37.9	1.09	18.3	1242	2.4	0.48	173.4	0.0420	0.75	0.50	35.6
Control	35.7	1.02	16.4	1292	2.3	0.55	126.0	0.0347	0.66	0.44	30.5
Control	35.1	0.83	16.9	653	2.4	0.39	106.6	0.0343	0.69	0.46	29.1
Control	36.9	0.62	17.6	543	2.5	0.36	91.6	0.0328	0.73	0.48	43.7
1x	35.3	0.47	17.5	281	2.4	0.31	72.6	0.0321	0.70	0.45	31.2
1x	38.3	0.52	19.1	405	2.6	0.36	88.6	0.0285	0.77	0.49	35.0
1x	38.9	0.59	18.6	334	2.6	0.33	88.4	0.0323	0.76	0.49	34.3
1x	39.7	0.60	18.8	376	2.5	0.37	86.7	0.0453	0.72	0.49	32.4
2x	38.3	0.45	19.9	358	2.5	0.33	82.8	0.0311	0.79	0.50	33.5
2x	36.6	0.72	19.5	319	2.4	0.34	96.7	0.0285	0.79	0.49	32.9
2x	33.6	0.43	17.1	302	2.4	0.31	73.4	0.0269	0.72	0.47	32.5
2x	37.2	0.48	18.3	294	2.6	0.33	85.7	0.0331	0.79	0.50	33.1

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

Table C-9. Nutrient Concentration in Plant Tissue at Mounier Golf Training Center at Weibring Golf Club, Normal, IL, July 18, 2017.

Lab ID	Boron PPM	Calcium %	Copper PPM	Iron PPM	Potassium %	Magnesium %	Manganese PPM	Sodium %	Phosphorus %	Sulfur %	Zinc PPM
Control	32.4	1.09	14.0	2351	1.86	0.59	94.6	0.073	0.54	0.36	26.1
Control	26.5	1.24	14.4	1446	2.06	0.60	103.1	0.068	0.53	0.35	22.9
Control	25.4	0.69	15.4	974	2.14	0.43	92.1	0.075	0.53	0.36	21.9
Control	25.6	0.57	15.3	598	2.24	0.37	59.2	0.074	0.59	0.38	25.2
1x	22.3	0.36	15.1	448	2.19	0.30	48.9	0.068	0.56	0.36	23.9
1x	28.2	0.37	18.4	336	2.40	0.31	53.7	0.069	0.70	0.44	30.1
1x	26.3	0.68	18.1	454	2.72	0.36	76.3	0.081	0.77	0.46	32.9
1x	23.8	0.48	15.6	309	2.35	0.30	57.4	0.086	0.65	0.41	29.1
2x	21.4	0.42	14.7	345	2.07	0.29	52.3	0.066	0.64	0.38	26.0
2x	24.6	0.40	17.7	216	2.55	0.32	57.3	0.079	0.81	0.45	32.7
2x	24.8	0.40	19.8	244	2.51	0.32	53.1	0.078	0.77	0.45	34.3
2x	25.6	0.48	17.9	267	2.68	0.33	61.8	0.084	0.81	0.46	32.3

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

Table C-10. Nutrient Concentration in Plant Tissue at Mounier Golf Training Center at Weibring Golf Club, Normal, IL, July 21, 2017.

Lab ID	Boron PPM	Calcium %	Copper PPM	Iron PPM	Potassium %	Magnesium %	Manganese PPM	Sodium %	Phosphorus %	Sulfur %	Zinc PPM
Control	23.8	1.84	13.5	1697	1.86	0.78	93.8	0.061	0.58	0.36	27.0
Control	23.2	1.85	14.1	1515	2.12	0.95	187.2	0.061	0.61	0.38	24.6
Control	21.3	0.84	14.7	795	2.11	0.49	69.1	0.060	0.65	0.39	25.1
Control	21.7	0.75	15.3	689	2.20	0.43	76.3	0.060	0.68	0.41	28.9
1x	22.5	0.62	16.0	545	2.29	0.42	58.1	0.066	0.72	0.42	28.2
1x	25.7	0.78	18.6	885	2.41	0.48	77.7	0.064	0.79	0.45	31.2
1x	22.9	0.60	28.7	553	2.22	0.40	60.4	0.064	0.72	0.43	29.7
1x	24.7	0.97	15.7	1030	2.0	0.54	80.5	0.066	0.65	0.40	28.2
2x	22.0	0.79	17.0	513	2.29	0.38	87.0	0.065	0.78	0.45	28.1
2x	22.3	0.77	16.6	735	2.09	0.48	73.1	0.060	0.74	0.42	27.4
2x	23.1	0.78	17.2	747	2.16	0.49	64.3	0.060	0.76	0.43	28.8
2x	21.3	0.57	16.0	456	2.18	0.39	53.5	0.061	0.75	0.42	28.1

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

Table C-11. Nutrient Concentration in Plant Tissue at Mounier Golf Training Center at Weibring Golf Club, Normal, IL, July 25, 2017.

Lab ID	Boron PPM	Calcium %	Copper PPM	Iron PPM	Potassium %	Magnesium %	Manganese PPM	Sodium %	Phosphorus %	Sulfur %	Zinc PPM
Control	28.2	2.72	12.1	3158	1.67	1.15	177.8	0.062	.045	0.27	26.7
Control	24.9	2.14	10.2	2697	1.62	0.94	134.3	0.056	0.41	0.25	23.7
Control	24.5	1.32	13.7	1477	2.09	0.62	93.7	0.066	0.54	0.30	22.9
Control	28.1	0.89	15.2	813	2.56	0.51	69.7	0.081	0.66	0.37	29.1
1x	27.0	0.71	15.0	900	2.57	0.42	82.8	0.086	0.69	0.37	29.9
1x	28.5	0.66	16.5	494	2.71	0.42	63.6	0.085	0.74	0.39	32.0
1x	27.2	0.96	15.9	902	2.48	0.47	82.1	0.079	0.70	0.38	30.4
1x	29.3	1.59	15.2	1533	2.36	0.64	122.8	0.081	0.66	0.36	30.1
2x	27.8	1.35	15.0	1303	2.35	0.59	109.0	0.082	0.65	0.35	29.4
2x	28.6	0.65	16.6	56	2.69	0.43	64.5	0.090	0.78	0.40	32.8
2x	22.5	0.49	12.6	312	2.14	0.33	45.4	0.071	0.63	0.34	26.8
2x	23.6	0.40	13.1	229	2.25	0.30	42.8	0.075	0.68	0.36	27.3

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

Table C-12. Nutrient Concentration in Plant Tissue at Mounier Golf Training Center at Weibring Golf Club, Normal, IL, July 28, 2017.

Lab ID	Boron PPM	Calcium %	Copper PPM	Iron PPM	Potassium %	Magnesium %	Manganese PPM	Sodium %	Phosphorus %	Sulfur %	Zinc PPM
Control	22.5	1.51	14.9	1774	1.74	0.70	128.2	0.052	0.60	0.27	21.4
Control	27.3	0.97	18.7	1300	2.11	0.53	131.2	0.056	0.81	0.35	30.4
Control	24.2	0.75	18.4	938	2.18	0.43	115.2	0.059	0.76	0.32	28.1
Control	24.8	0.62	20.1	483	2.29	0.35	109.5	0.057	0.82	0.34	25.4
1x	30.4	0.64	23.0	579	3.31	0.43	127.4	0.094	0.97	0.39	29.1
1x	26.6	1.00	21.2	981	2.96	0.52	123.1	0.076	0.82	0.34	25.4
1x	30.8	2.00	18.9	1738	2.57	0.84	146.8	0.073	0.81	0.34	24.5
1x	28.9	1.17	20.6	867	3.04	0.68	131.6	0.099	0.83	0.36	24.3
2x	32.0	0.80	22.9	782	3.24	0.51	127.1	0.086	1.01	.041	29.3
2x	31.5	0.68	24.1	610	3.44	0.47	132.5	0.090	1.06	0.41	30.4
2x	31.8	0.75	25.11	728	3.41	0.47	129.9	0.089	1.04	0.41	31.2
2x	33.4	0.69	23.2	522	3.65	0.44	135.1	0.097	1.12	0.43	31.8

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

Table C-13. Nutrient Concentration in Plant Tissue at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL, June 20, 2017.

Lab ID	Boron PPM	Calcium %	Copper PPM	Iron PPM	Potassium %	Magnesium %	Manganese PPM	Sodium %	Phosphorus %	Sulfur %	Zinc PPM
Control	17.3	.73	11.2	1058	1.16	.4	39.54	.103	.30	.23	22.43
Control	18.7	.83	12.7	1442	1.11	.4	53.95	.102	.30	.24	22.56
Control	16.8	.62	12.3	779.8	1.12	.4	39.37	.098	.31	.25	22.75
Control	19.0	.89	13.3	1030	1.23	.5	55.25	.102	.33	.27	25.36
1x	20.3	.73	13.2	318.1	1.34	.4	43.54	.084	34	.28	24.98
1x	20.7	.89	13.3	453.4	1.27	.5	44.63	.080	.35	.27	24.71
1x	17.7	.71	12.5	333.2	1.24	.4	34.82	.084	.32	.24	21.02
1x	19.4	.83	4.2	478.2	1.21	.4	40.09	.085	.31	.24	22.14
2x	16.4	.75	9.3	412.3	1.22	.4	40.99	.089	.31	.27	22.85
2x	17.8	.79	12.8	453.4	1.25	.4	39.11	.085	.32	.30	22.95
2x	19.5	.76	7.3	260.6	1.34	.4	39.59	.089	.31	.29	23.80
2x	23.1	.72	15.3	294.1	1.32	.4	45.34	.087	.32	.28	24.04

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

Table C-14. Nutrient Concentration in Plant Tissue at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL, June 23, 2017.

Lab ID	Boron PPM	Calcium %	Copper PPM	Iron PPM	Potassium %	Magnesium %	Manganese PPM	Sodium %	Phosphorus %	Sulfur %	Zinc PPM
Control	22.3	.88	12.2	734.8	1.57	.5	48.40	.149	.39	.37	33.57
Control	15.0	.64	8.5	440.8	1.24	.4	36.94	.122	.33	.26	24.79
Control	17.2	.77	7.4	732.9	1.13	.4	44.64	.107	.30	.24	24.63
Control	16.0	.70	8.0	404.9	1.22	.4	39.68	.109	.33	.26	25.48
1x	14.8	.58	7.6	263.9	1.30	.3	37.19	.115	.33	.26	24.35
1x	16.0	.69	8.2	440.2	1.27	.4	42.64	.110	.35	.27	25.72
1x	16.2	.76	9.4	407.7	1.31	.4	42.59	.118	.35	.26	26.16
1x	15.4	.68	7.8	476.9	1.16	.4	40.82	.103	.30	.23	23.64
2x	14.3	.62	8.0	385.2	1.22	.3	38.93	.113	.32	.26	25.83
2x	16.1	.81	13.7	344.9	1.69	.4	50.64	.142	.40	.35	32.08
2x	20.1	.79	15.3	318.1	1.83	.4	55.25	.158	.43	.38	35.29
2x	20.0	.69	13.8	290.7	1.68	.4	55.93	.150	.41	.35	32.53

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

Table C-15. Nutrient Concentration in Plant Tissue at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL, June 27, 2017.

Lab ID	Boron PPM	Calcium %	Copper PPM	Iron PPM	Potassium %	Magnesium %	Manganese PPM	Sodium %	Phosphorus %	Sulfur %	Zinc PPM
Control	23.9	0.59	7.7	970	1.26	0.32	40.2	0.125	0.30	0.23	24.9
Control	27.5	0.63	8.9	935	1.44	0.36	44.7	0.147	0.34	0.28	24.7
Control	28.8	0.70	9.5	665	1.56	0.39	48.8	0.153	0.36	0.28	26.73
Control	25.4	0.61	8.9	510	1.56	0.34	39.3	0.149	0.35	0.26	24.0
1x	28.8	0.60	9.9	340	1.69	0.34	44.6	0.172	0.40	0.30	26.0
1x	25.8	0.62	8.7	397	1.53	0.33	42.6	0.150	0.37	0.27	24.0
1x	23.0	0.63	5.5	438	1.12	0.32	35.8	0.108	0.27	0.19	18.9
1x	27.7	0.82	7.4	615	1.39	0.41	48.8	0.125	0.32	0.22	24.1
2x	27.7	0.65	8.7	513	1.59	0.35	40.8	0.161	0.36	0.28	25.2
2x	23.0	0.56	7.4	244	1.51	0.31	31.0	0.149	0.31	0.25	21.2
2x	24.9	0.48	7.0	182	1.46	0.28	29.2	0.149	0.30	0.25	21.2
2x	32.6	0.57	9.5	308	1.75	0.34	43.6	0.181	0.29	0.34	24.9

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

Table C-16. Nutrient Concentration in Plant Tissue at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL, June 30, 2017.

Lab ID	Boron PPM	Calcium %	Copper PPM	Iron PPM	Potassium %	Magnesium %	Manganese PPM	Sodium %	Phosphorus %	Sulfur %	Zinc PPM
Control	15.7	0.66	9.2	1629	0.78	0.43	73.6	0.090	0.27	0.14	19.3
Control	14.6	0.86	7.0	1346	0.97	0.43	75.2	0.111	0.23	0.16	19.6
Control	16.6	1.22	9.3	1505	1.16	0.60	97.4	0.129	0.26	0.18	21.8
Control	17.63	1.21	10.6	1514	1.34	0.63	104.3	0.147	0.29	2.0	23.7
1x	20.1	1.17	12.5	1363	1.71	0.61	117.1	0.190	0.38	0.28	27.2
1x	23.2	1.87	11.6	2067	1.28	0.90	125.8	0.147	0.32	0.22	27.69
1x	19.7	2.03	8.7	1925	1.06	1.00	121.6	0.119	0.27	0.18	26.23
1x	18.3	2.06	9.9	2234	1.19	1.00	121.6	0.131	0.24	0.17	26.2
2x	16.7	1.13	10.2	1143	1.32	0.57	99.2	0.150	0.28	0.20	21.4
2x	20.5	1.33	12.7	1413	1.57	0.67	121.5	0.179	0.34	0.27	25.6
2x	21.6	0.92	13.0	757	1.66	0.50	110.7	0.186	0.35	0.29	25.87
2x	19.3	0.70	12.4	634	1.38	0.38	101.7	0.163	0.38	0.30	25.9

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

Table C-17. Nutrient Concentration in Plant Tissue at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL, July 4, 2017.

Lab ID	Boron PPM	Calcium %	Copper PPM	Iron PPM	Potassium %	Magnesium %	Manganese PPM	Sodium %	Phosphorus %	Sulfur %	Zinc PPM
Control	16.3	0.68	9.9	1424	0.8	0.36	49.1	0.087	0.24	0.16	25.4
Control	16.6	0.79	9.0	1113	1.0	0.14	52.5	0.112	0.29	0.19	26.0
Control	18.0	0.81	9.9	1110	1.1	0.46	57.3	0.126	0.33	0.22	27.4
Control	17.4	0.74	9.7	745	1.1	0.42	52.7	0.122	0.33	0.22	26.7
1x	19.4	0.85	10.0	706	1.2	0.47	51.0	0.130	0.36	0.26	25.5
1x	17.9	1.12	8.4	1123	1.0	0.62	60.7	0.100	0.30	0.20	23.7
1x	19.3	1.34	8.8	1367	1.0	0.69	71.0	0.096	0.29	0.19	25.3
1x	22.4	1.54	9.5	1584	1.2	0.74	84.5	0.119	0.35	0.23	31.4
2x	18.0	0.91	8.9	890	1.2	0.47	56.9	0.136	0.32	0.23	26.0
2x	18.4	0.83	8.6	599	1.2	0.42	49.4	0.130	0.33	0.25	24.7
2x	17.8	0.68	9.1	519	1.2	0.39	47.1	0.137	0.33	0.27	24.6
2x	20.0	0.57	10.0	453	1.4	0.36	44.7	0.151	0.39	0.31	27.0

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

Table C-18. Nutrient Concentration in Plant Tissue at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL, July 7, 2017.

Lab ID	Boron PPM	Calcium %	Copper PPM	Iron PPM	Potassium %	Magnesium %	Manganese PPM	Sodium %	Phosphorus %	Sulfur %	Zinc PPM
Control	27.8	0.84	12.3	864	1.4	0.49	100.5	0.136	0.47	0.29	32.0
Control	24.9	1.12	10.6	1877	1.2	0.57	119.9	0.115	0.38	0.22	27.4
Control	24.3	1.42	10.4	1270	1.1	0.63	121.9	0.105	0.37	0.22	25.4
Control	25.0	1.04	12.8	960	1.4	0.53	128.0	0.122	0.44	0.27	27.4
1x	22.5	1.12	11.1	872	1.3	0.64	136.2	0.123	0.38	0.23	20.0
1x	22.7	0.88	11.9	677	1.4	0.43	127.2	0.127	0.44	0.26	23.9
1x	29.3	1.07	13.5	1073	1.5	0.65	148.4	0.132	0.49	0.28	27.2
1x	21.9	1.01	11.5	993	1.3	0.56	138.2	0.116	0.35	0.20	20.6
2x	23.0	0.88	12.0	986	1.3	0.50	116.2	0.125	0.38	0.24	22.1
2x	34.1	0.79	14.2	803	1.4	0.46	127.3	0.140	0.49	0.32	26.8
2x	26.4	0.63	12.3	489	1.4	0.39	105.8	0.136	0.37	0.26	19.8
2x	33.9	0.54	14.3	556	1.5	0.38	122.5	0.152	0.47	0.32	26.5

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

Table C-19. Nutrient Concentration in Plant Tissue at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL, July 11, 2017.

Lab ID	Boron PPM	Calcium %	Copper PPM	Iron PPM	Potassium %	Magnesium %	Manganese PPM	Sodium %	Phosphorus %	Sulfur %	Zinc PPM
Control	11.76	0.51	8.9	776	1.01	0.32	47.8	1.107	0.33	0.21	25.3
Control	12.32	0.58	10.9	812	1.20	0.37	58.2	0.132	0.40	0.26	26.6
Control	9.04	0.67	9.6	577	1.32	0.43	56.6	0.154	0.32	.021	22.3
Control	11.6	0.64	10.9	621	1.44	0.40	59.3	0.162	0.38	0.25	25.7
1x	10.55	0.62	11.7	396	1.67	0.41	58.0	0.170	0.44	0.30	26.0
1x	11.38	0.69	10.3	489	1.43	0.43	58.5	0.146	0.42	0.27	25.7
1x	9.90	0.89	10.3	560	1.43	0.51	62.5	0.147	0.39	0.25	24.3
1x	10.37	0.93	11.5	784	1.48	0.56	78.0	0.154	0.36	0.23	25.5
2x	10.75	0.68	11.4	441	1.49	0.40	57.7	0.162	0.41	0.28	25.7
2x	10.43	0.57	11.0	428	1.47	0.37	51.1	0.158	0.40	0.28	25.0
2x	12.49	0.56	12.9	381	1.72	0.40	57.3	0.183	0.46	0.34	29.0
2x	12.13	0.47	11.7	268	1.54	0.35	52.7	0.164	0.45	0.33	28.6

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

Table C-20. Nutrient Concentration in Plant Tissue at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL, July 13, 2017.

Lab ID	Boron PPM	Calcium %	Copper PPM	Iron PPM	Potassium %	Magnesium %	Manganese PPM	Sodium %	Phosphorus %	Sulfur %	Zinc PPM
Control	26.4	0.86	15.3	955	2.33	0.54	87.3	0.209	0.62	0.36	344.2
Control	24.1	0.80	14.5	645	2.20	0.51	89.5	0.188	0.58	0.33	398.3
Control	34.8	0.76	11.4	719	1.65	.044	93.7	0.413	0.59	0.35	515.2
Control	30.8	0.75	11.5	570	1.73	0.43	86.3	0.145	0.59	0.34	522.5
1x	37.3	0.70	12.2	409	1.90	0.41	81.0	0.150	0.65	0.40	529.0
1x	37.7	0.80	13.0	559	1.99	0.47	87.4	0.155	0.69	0.40	508.2
1x	37.2	1.03	12.5	761	1.81	0.56	98.2	0.141	0.64	0.36	494.3
1x	34.4	1.09	12.5	981	1.79	0.58	110.1	0.142	0.57	0.33	509.2
2x	41.9	0.87	14.3	586	2.02	0.51	102.8	0.171	0.71	0.42	619.1
2x	46.5	0.72	13.7	510	2.05	0.43	89.0	0.173	0.76	0.47	709.9
2x	39.4	0.68	14.3	471	2.08	0.42	90.2	0.177	0.64	0.43	553.5
2x	45.0	0.65	13.8	366	2.09	0.43	88.1	0.185	0.69	0.46	574.3

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

Table C-21. Nutrient Concentration in Plant Tissue at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL, July 17, 2017.

Lab ID	Boron PPM	Calcium %	Copper PPM	Iron PPM	Potassium %	Magnesium %	Manganese PPM	Sodium %	Phosphorus %	Sulfur %	Zinc PPM
Control	30.7	0.69	14.2	473	2.19	0.43	54.6	0.156	0.55	0.33	150.6
Control	30.7	0.66	14.6	292	2.21	0.40	54.5	0.151	0.55	0.35	150.6
Control	30.7	0.67	14.8	325	2.22	0.40	53.5	0.153	0.55	0.36	164.0
Control	28.4	0.61	13.3	215	2.05	0.37	46.4	0.144	0.51	0.33	152.8
1x	32.6	0.58	13.6	163	2.15	0.38	47.7	0.153	0.53	0.37	140.5
1x	27.7	0.58	13.6	178	2.10	0.36	41.4	0.141	0.52	0.347	134.1
1x	35.4	0.68	15.7	320	2.10	0.40	53.0	0.143	0.57	0.37	163.5
1x	32.8	0.71	15.4	297	2.24	0.42	54.8	0.148	0.55	0.35	151.2
2x	13.6	0.81	13.2	156	1.73	0.35	24.3	0.006	0.21	0.14	25.2
2x	11.0	0.56	7.6	91	1.76	0.22	18.6	0.003	0.20	0.12	19.6
2x	27.0	0.59	13.2	169	1.99	0.35	41.5	0.145	0.49	0.34	137.4
2x	30.2	0.55	13.0	146	2.04	0.34	42.3	0.151	0.49	0.35	134.8

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

Table C-22. Nutrient Concentration in Plant Tissue at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL, July 20, 2017.

Lab ID	Boron PPM	Calcium %	Copper PPM	Iron PPM	Potassium %	Magnesium %	Manganese PPM	Sodium %	Phosphorus %	Sulfur %	Zinc PPM
Control	27.4	0.75	11.9	1136	1.4	0.42	53.0	0.106	0.51	0.32	84.0
Control	25.7	0.63	11.7	341	1.5	0.38	52.2	0.115	0.56	0.36	79.9
Control	26.2	0.58	12.3	285	1.6	0.38	40.7	0.123	0.58	0.37	83.2
Control	25.6	0.61	11.5	350	1.5	0.39	39.9	0.118	0.53	0.35	77.4
1x	22.0	0.55	11.5	321	1.6	0.37	38.0	0.110	0.49	0.33	60.9
1x	23.8	0.75	10.7	480	1.4	0.44	38.1	0.101	0.50	0.32	61.9
1x	21.4	0.87	9.5	513	1.3	0.54	42.5	0.104	0.43	0.27	55.3
1x	21.6	0.58	10.7	294	1.5	0.38	37.7	0.118	0.48	0.30	62.7
2x	27.6	0.60	12.2	326	1.6	0.39	41.2	0.118	0.55	0.38	77.0
2x	26.0	0.71	12.0	429	1.5	0.42	41.7	0.117	0.48	0.34	63.6
2x	27.1	0.61	13.9	383	1.6	0.41	42.0	0.126	0.44	0.34	55.8
2x	30.7	0.66	15.0	415	1.7	0.44	46.4	0.134	0.48	0.36	58.2

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

Table C-23. Nutrient Concentration in Plant Tissue at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL, July 24, 2017.

Lab ID	Boron PPM	Calcium %	Copper PPM	Iron PPM	Potassium %	Magnesium %	Manganese PPM	Sodium %	Phosphorus %	Sulfur %	Zinc PPM
Control	32.8	0.55	12.7	157	2.04	0.35	45.3	0.164	0.47	0.36	126.1
Control	32.0	0.48	12.9	126	1.97	0.33	45.4	0.159	0.46	0.35	116.3
Control	21.6	0.60	13.6	254	1.49	0.37	41.4	0.097	0.48	0.31	62.0
Control	21.9	0.60	13.8	381	1.49	0.37	44.4	0.096	0.48	0.30	61.8
1x	24.8	0.58	14.7	243	1.64	0.38	42.6	0.105	0.53	0.34	56.0
1x	22.2	0.60	14.0	271	1.52	0.36	40.8	0.095	0.49	0.31	53.6
1x	22.4	0.72	13.1	327	1.50	0.40	40.3	0.099	0.49	0.30	54.9
1x	22.9	0.64	14.5	306	1.61	0.39	46.8	0.106	0.50	0.30	56.5
2x	23.4	0.60	14.9	254	1.67	0.38	41.3	0.113	0.53	0.35	64.3
2x	21.9	0.51	13.6	218	1.47	0.33	37.3	0.106	0.45	0.30	52.2
2x	27.9	0.53	15.1	230	1.68	0.37	42.7	0.130	0.50	0.36	53.6
2x	27.3	0.48	15.3	177	1.69	0.34	42.4	0.133	0.49	0.34	52.5

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

Table C-24. Nutrient Concentration in Plant Tissue at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL, July 27, 2017.

Lab ID	Boron PPM	Calcium %	Copper PPM	Iron PPM	Potassium %	Magnesium %	Manganese PPM	Sodium %	Phosphorus %	Sulfur %	Zinc PPM
Control	15.5	0.54	13.5	369	1.44	0.34	36.9	0.085	0.52	0.31	57.7
Control	14.8	0.55	14.0	203	1.53	0.35	37.1	0.087	0.52	0.33	52.6
Control	15.1	0.55	14.2	166	1.52	0.34	35.3	0.090	0.53	0.34	52.9
Control	16.2	0.55	14.7	181	1.51	0.34	37.5	0.090	0.53	0.35	53.9
1x	17.0	0.49	14.8	137	1.55	0.34	34.3	0.103	0.52	0.36	50.0
1x	17.0	0.53	13.6	158	1.42	0.33	32.7	0.093	0.48	0.33	45.1
1x	16.8	0.54	13.3	144	1.47	0.34	30.3	0.098	0.51	0.33	45.9
1x	17.7	0.56	15.0	176	1.54	0.35	38.8	0.104	0.53	0.34	49.2
2x	15.7	0.50	14.6	168	1.47	0.32	34.4	0.094	0.49	0.33	47.5
2x	17.9	0.48	12.9	201	1.27	0.29	33.1	0.092	0.44	0.30	45.8
2x	20.3	0.48	15.8	168	1.50	0.33	36.9	0.115	0.50	0.36	47.2
2x	18.9	0.47	12.6	231	1.42	0.30	36.7	0.108	0.45	0.31	43.7

Control Plot
1x- (Horticultural Rate)
2x- (Agronomic Rate)

APPENDIX D: CHLOROPHYLL DATA STATISTICS

Table D-1. Chlorophyll Correlation with Boron (B) at Mounier Golf Training Center at Weibring Golf Club, Normal, IL.

Correlations

		B_C	B_1x	B_2x	Chlorophyll_a	Chlorophyll_b	Chlorophyll_ab	Total_Carotenoids
B_C	Pearson Correlation	1	.[a]	.[a]	-.474**	-.151	-.263	.124
	Sig. (2-tailed)		.	.	.001	.305	.071	.400
	N	48	0	0	48	48	48	48
B_1x	Pearson Correlation	.[a]	1	.[a]	.048	.056	.054	-.003
	Sig. (2-tailed)	.		.	.744	.708	.718	.984
	N	0	48	0	48	48	48	48
B_2x	Pearson Correlation	.[a]	.[a]	1	-.307*	-.134	-.193	.098
	Sig. (2-tailed)	.	.		.034	.363	.189	.507
	N	0	0	48	48	48	48	48
Chlorophyll_a	Pearson Correlation	-.474**	.048	-.307*	1	.946**	.975**	-.897**
	Sig. (2-tailed)	.001	.744	.034		.000	.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_b	Pearson Correlation	-.151	.056	-.134	.946**	1	.994**	-.971**
	Sig. (2-tailed)	.305	.708	.363	.000		.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_ab	Pearson Correlation	-.263	.054	-.193	.975**	.994**	1	-.958**
	Sig. (2-tailed)	.071	.718	.189	.000	.000		.000
	N	48	48	48	144	144	144	144
Total_Carotenoids	Pearson Correlation	.124	-.003	.098	-.897**	-.971**	-.958**	1
	Sig. (2-tailed)	.400	.984	.507	.000	.000	.000	
	N	48	48	48	144	144	144	144

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D-2. Chlorophyll Correlation with Calcium (Ca) at Mounier Golf Training Center at Weibring Golf Club, Normal, IL.

Correlations

		Ca_C	Ca_1x	Ca_2x	Chlorophyll_a	Chlorophyll_b	Chlorophyll_ab	Total_Carotenoids
Ca_C	Pearson Correlation	1	.[a]	.[a]	-.047	-.109	-.091	.128
	Sig. (2-tailed)		.	.	.750	.460	.538	.386
	N	48	0	0	48	48	48	48
Ca_1x	Pearson Correlation	.[a]	1	.[a]	-.176	-.209	-.200	.275
	Sig. (2-tailed)	.		.	.232	.153	.173	.059
	N	0	48	0	48	48	48	48
Ca_2x	Pearson Correlation	.[a]	.[a]	1	-.423**	-.435**	-.434**	.437**
	Sig. (2-tailed)	.	.		.003	.002	.002	.002
	N	0	0	48	48	48	48	48
Chlorophyll_a	Pearson Correlation	-.047	-.176	-.423**	1	.946**	.975**	-.897**
	Sig. (2-tailed)	.750	.232	.003		.000	.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_b	Pearson Correlation	-.109	-.209	-.435**	.946**	1	.994**	-.971**
	Sig. (2-tailed)	.460	.153	.002	.000		.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_ab	Pearson Correlation	-.091	-.200	-.434**	.975**	.994**	1	-.958**
	Sig. (2-tailed)	.538	.173	.002	.000	.000		.000
	N	48	48	48	144	144	144	144
Total_Carotenoids	Pearson Correlation	.128	.275	.437**	-.897**	-.971**	-.958**	1
	Sig. (2-tailed)	.386	.059	.002	.000	.000	.000	
	N	48	48	48	144	144	144	144

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D-3. Chlorophyll Correlation with Copper (Cu) at Mounier Golf Training Center at Weibring Golf Club, Normal, IL.

Correlations

		Cu_C	Cu_1x	Cu_2x	Chlorophyll_a	Chlorophyll_b	Chlorophyll_ab	Total_Carotenoids
Cu_C	Pearson Correlation	1	.[a]	.[a]	-.505**	-.507**	-.519**	.498**
	Sig. (2-tailed)		.	.	.000	.000	.000	.000
	N	48	0	0	48	48	48	48
Cu_1x	Pearson Correlation	.[a]	1	.[a]	-.237	-.240	-.240	.246
	Sig. (2-tailed)	.		.	.105	.101	.100	.092
	N	0	48	0	48	48	48	48
Cu_2x	Pearson Correlation	.[a]	.[a]	1	-.317*	-.344*	-.337*	.321*
	Sig. (2-tailed)	.	.		.028	.017	.019	.026
	N	0	0	48	48	48	48	48
Chlorophyll_a	Pearson Correlation	-.505**	-.237	-.317*	1	.946**	.975**	-.897**
	Sig. (2-tailed)	.000	.105	.028		.000	.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_b	Pearson Correlation	-.507**	-.240	-.344*	.946**	1	.994**	-.971**
	Sig. (2-tailed)	.000	.101	.017	.000		.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_ab	Pearson Correlation	-.519**	-.240	-.337*	.975**	.994**	1	-.958**
	Sig. (2-tailed)	.000	.100	.019	.000	.000		.000
	N	48	48	48	144	144	144	144
Total_Carotenoids	Pearson Correlation	.498**	.246	.321*	-.897**	-.971**	-.958**	1
	Sig. (2-tailed)	.000	.092	.026	.000	.000	.000	
	N	48	48	48	144	144	144	144

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D-4. Chlorophyll Correlation with Iron (Fe) at Mounier Golf Training Center at Weibring Golf Club, Normal, IL.

Correlations

		Cu_C	Cu_1x	Cu_2x	Chlorophyll_a	Chlorophyll_b	Chlorophyll_ab	Total_Carotenoids
Cu_C	Pearson Correlation	1	.[a]	.[a]	-.530**	-.534**	-.546**	.513**
	Sig. (2-tailed)		.	.	.000	.000	.000	.000
	N	48	0	0	48	48	48	48
Cu_1x	Pearson Correlation	.[a]	1	.[a]	-.589**	-.613**	-.609**	.590**
	Sig. (2-tailed)	.		.	.000	.000	.000	.000
	N	0	48	0	48	48	48	48
Cu_2x	Pearson Correlation	.[a]	.[a]	1	-.578**	-.577**	-.581**	.537**
	Sig. (2-tailed)	.	.		.000	.000	.000	.000
	N	0	0	48	48	48	48	48
Chlorophyll_a	Pearson Correlation	-.530**	-.589**	-.578**	1	.946**	.975**	-.897**
	Sig. (2-tailed)	.000	.000	.000		.000	.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_b	Pearson Correlation	-.534**	-.613**	-.577**	.946**	1	.994**	-.971**
	Sig. (2-tailed)	.000	.000	.000	.000		.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_ab	Pearson Correlation	-.546**	-.609**	-.581**	.975**	.994**	1	-.958**
	Sig. (2-tailed)	.000	.000	.000	.000	.000		.000
	N	48	48	48	144	144	144	144
Total_Carotenoids	Pearson Correlation	.513**	.590**	.537**	-.897**	-.971**	-.958**	1
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	
	N	48	48	48	144	144	144	144

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D-5. Chlorophyll Corrleation with Potassium (K) at Mounier Golf Training Center at Weibring Golf Club, Normal, IL.

Correlations

		K_C	K_1x	K_2x	Chlorophyll_a	Chlorophyll_b	Chlorophyll_ab	Total_Carotenoids
K_C	Pearson Correlation	1	.[a]	.[a]	.106	.098	.103	-.052
	Sig. (2-tailed)		.	.	.475	.508	.487	.726
	N	48	0	0	48	48	48	48
K_1x	Pearson Correlation	.[a]	1	.[a]	.029	.021	.024	.018
	Sig. (2-tailed)	.		.	.844	.886	.871	.903
	N	0	48	0	48	48	48	48
K_2x	Pearson Correlation	.[a]	.[a]	1	.040	.015	.023	.014
	Sig. (2-tailed)	.	.		.786	.922	.876	.925
	N	0	0	48	48	48	48	48
Chlorophyll_a	Pearson Correlation	.106	.029	.040	1	.946**	.975**	-.897**
	Sig. (2-tailed)	.475	.844	.786		.000	.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_b	Pearson Correlation	.098	.021	.015	.946**	1	.994**	-.971**
	Sig. (2-tailed)	.508	.886	.922	.000		.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_ab	Pearson Correlation	.103	.024	.023	.975**	.994**	1	-.958**
	Sig. (2-tailed)	.487	.871	.876	.000	.000		.000
	N	48	48	48	144	144	144	144
Total_Carotenoids	Pearson Correlation	-.052	.018	.014	-.897**	-.971**	-.958**	1
	Sig. (2-tailed)	.726	.903	.925	.000	.000	.000	
	N	48	48	48	144	144	144	144

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D-6. Chlorophyll Correlation with Magnesium (Mg) at Mounier Golf Training Center at Weibring Golf Club, Normal, IL.

Correlations

		Mg_C	Mg_1x	Mg_2x	Chlorophyll_a	Chlorophyll_b	Chlorophyll_ab	Total_Carotenoids
Mg_C	Pearson Correlation	1	.[a]	.[a]	-.222	-.279	-.267	.285*
	Sig. (2-tailed)		.	.	.129	.055	.067	.050
	N	48	0	0	48	48	48	48
Mg_1x	Pearson Correlation	.[a]	1	.[a]	-.295*	-.280	-.286*	.324*
	Sig. (2-tailed)	.		.	.041	.054	.048	.025
	N	0	48	0	48	48	48	48
Mg_2x	Pearson Correlation	.[a]	.[a]	1	-.246	-.254	-.253	.268
	Sig. (2-tailed)	.	.		.091	.082	.083	.065
	N	0	0	48	48	48	48	48
Chlorophyll_a	Pearson Correlation	-.222	-.295*	-.246	1	.946**	.975**	-.897**
	Sig. (2-tailed)	.129	.041	.091		.000	.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_b	Pearson Correlation	-.279	-.280	-.254	.946**	1	.994**	-.971**
	Sig. (2-tailed)	.055	.054	.082	.000		.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_ab	Pearson Correlation	-.267	-.286*	-.253	.975**	.994**	1	-.958**
	Sig. (2-tailed)	.067	.048	.083	.000	.000		.000
	N	48	48	48	144	144	144	144
Total_Carotenoids	Pearson Correlation	.285*	.324*	.268	-.897**	-.971**	-.958**	1
	Sig. (2-tailed)	.050	.025	.065	.000	.000	.000	
	N	48	48	48	144	144	144	144

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D-7. Chlorophyll Correlation with Manganese (Mn) at Mounier Golf Training Center at Weibring Golf Club, Normal, IL.

Correlations

		Mn_C	Mn_1x	Mn_2x	Chlorophyll_a	Chlorophyll_b	Chlorophyll_ab	Total_Carotenoids
Mn_C	Pearson Correlation	1	.[a]	.[a]	-.192	-.046	-.096	-.003
	Sig. (2-tailed)		.	.	.192	.757	.518	.986
	N	48	0	0	48	48	48	48
Mn_1x	Pearson Correlation	.[a]	1	.[a]	-.225	-.250	-.243	.186
	Sig. (2-tailed)	.		.	.124	.087	.096	.205
	N	0	48	0	48	48	48	48
Mn_2x	Pearson Correlation	.[a]	.[a]	1	-.312*	-.285*	-.296*	.162
	Sig. (2-tailed)	.	.		.031	.049	.041	.273
	N	0	0	48	48	48	48	48
Chlorophyll_a	Pearson Correlation	-.192	-.225	-.312*	1	.946**	.975**	-.897**
	Sig. (2-tailed)	.192	.124	.031		.000	.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_b	Pearson Correlation	-.046	-.250	-.285*	.946**	1	.994**	-.971**
	Sig. (2-tailed)	.757	.087	.049	.000		.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_ab	Pearson Correlation	-.096	-.243	-.296*	.975**	.994**	1	-.958**
	Sig. (2-tailed)	.518	.096	.041	.000	.000		.000
	N	48	48	48	144	144	144	144
Total_Carotenoids	Pearson Correlation	-.003	.186	.162	-.897**	-.971**	-.958**	1
	Sig. (2-tailed)	.986	.205	.273	.000	.000	.000	
	N	48	48	48	144	144	144	144

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed)

Table D-8. Chlorophyll Correlation with Sodium (Na) at Mounier Golf Training Center at Weibring Golf Club, Normal, IL.

Correlations

		Na_C	Na_1x	Na_2x	Chlorophyll_a	Chlorophyll_b	Chlorophyll_ab	Total_Carotenoids
Na_C	Pearson Correlation	1	.[a]	.[a]	-.383[**]	-.473[**]	-.455[**]	.503[**]
	Sig. (2-tailed)		.	.	.007	.001	.001	.000
	N	48	0	0	48	48	48	48
Na_1x	Pearson Correlation	.[a]	1	.[a]	-.424[**]	-.564[**]	-.522[**]	.583[**]
	Sig. (2-tailed)	.		.	.003	.000	.000	.000
	N	0	48	0	48	48	48	48
Na_2x	Pearson Correlation	.[a]	.[a]	1	-.210	-.237	-.230	.268
	Sig. (2-tailed)	.	.		.151	.105	.116	.065
	N	0	0	48	48	48	48	48
Chlorophyll_a	Pearson Correlation	-.383[**]	-.424[**]	-.210	1	.946[**]	.975[**]	-.897[**]
	Sig. (2-tailed)	.007	.003	.151		.000	.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_b	Pearson Correlation	-.473[**]	-.564[**]	-.237	.946[**]	1	.994[**]	-.971[**]
	Sig. (2-tailed)	.001	.000	.105	.000		.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_ab	Pearson Correlation	-.455[**]	-.522[**]	-.230	.975[**]	.994[**]	1	-.958[**]
	Sig. (2-tailed)	.001	.000	.116	.000	.000		.000
	N	48	48	48	144	144	144	144
Total_Carotenoids	Pearson Correlation	.503[**]	.583[**]	.268	-.897[**]	-.971[**]	-.958[**]	1
	Sig. (2-tailed)	.000	.000	.065	.000	.000	.000	
	N	48	48	48	144	144	144	144

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table D-9. Chlorophyll Correlation with Phosphorus (P) at Mounier Golf Training Center at Weibring Golf Club, Normal, IL.

Correlations

		P_C	P_1x	P_2x	Chlorophyll_a	Chlorophyll_b	Chlorophyll_ab	Total_Carotenoids
P_C	Pearson Correlation	1	.[a]	.[a]	-.560**	-.572**	-.583**	.559**
	Sig. (2-tailed)		.	.	.000	.000	.000	.000
	N	48	0	0	48	48	48	48
P_1x	Pearson Correlation	.[a]	1	.[a]	-.520**	-.542**	-.538**	.481**
	Sig. (2-tailed)	.		.	.000	.000	.000	.001
	N	0	48	0	48	48	48	48
P_2x	Pearson Correlation	.[a]	.[a]	1	-.485**	-.507**	-.503**	.466**
	Sig. (2-tailed)	.	.		.000	.000	.000	.001
	N	0	0	48	48	48	48	48
Chlorophyll_a	Pearson Correlation	-.560**	-.520**	-.485**	1	.946**	.975**	-.897**
	Sig. (2-tailed)	.000	.000	.000		.000	.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_b	Pearson Correlation	-.572**	-.542**	-.507**	.946**	1	.994**	-.971**
	Sig. (2-tailed)	.000	.000	.000	.000		.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_ab	Pearson Correlation	-.583**	-.538**	-.503**	.975**	.994**	1	-.958**
	Sig. (2-tailed)	.000	.000	.000	.000	.000		.000
	N	48	48	48	144	144	144	144
Total_Carotenoids	Pearson Correlation	.559**	.481**	.466**	-.897**	-.971**	-.958**	1
	Sig. (2-tailed)	.000	.001	.001	.000	.000	.000	
	N	48	48	48	144	144	144	144

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D-10. Chlorophyll Correlation with Sulfur (S) at Mounier Golf Training Center at Weibring Golf Club, Normal, IL.

Correlations

		S_C	S_1x	S_2x	Chlorophyll_a	Chlorophyll_b	Chlorophyll_ab	Total_Carotenoids
S_C	Pearson Correlation	1	.[a]	.[a]	-.253	-.266	-.269	.259
	Sig. (2-tailed)		.	.	.083	.067	.065	.076
	N	48	0	0	48	48	48	48
S_1x	Pearson Correlation	.[a]	1	.[a]	-.259	-.215	-.231	.240
	Sig. (2-tailed)	.		.	.075	.142	.115	.100
	N	0	48	0	48	48	48	48
S_2x	Pearson Correlation	.[a]	.[a]	1	-.185	-.184	-.186	.196
	Sig. (2-tailed)	.	.		.208	.209	.206	.183
	N	0	0	48	48	48	48	48
Chlorophyll_a	Pearson Correlation	-.253	-.259	-.185	1	.946**	.975**	-.897**
	Sig. (2-tailed)	.083	.075	.208		.000	.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_b	Pearson Correlation	-.266	-.215	-.184	.946**	1	.994**	-.971**
	Sig. (2-tailed)	.067	.142	.209	.000		.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_ab	Pearson Correlation	-.269	-.231	-.186	.975**	.994**	1	-.958**
	Sig. (2-tailed)	.065	.115	.206	.000	.000		.000
	N	48	48	48	144	144	144	144
Total_Carotenoids	Pearson Correlation	.259	.240	.196	-.897**	-.971**	-.958**	1
	Sig. (2-tailed)	.076	.100	.183	.000	.000	.000	
	N	48	48	48	144	144	144	144

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D-11. Chlorophyll Correlation with Zinc (Zn) at Mounier Golf Training Center at Weibring Golf Club, Normal, IL.

Correlations

		Zn_C	Zn_1x	Zn_2x	Chlorophyll_a	Chlorophyll_b	Chlorophyll_ab	Total_Carotenoids
Zn_C	Pearson Correlation	1	.[a]	.[a]	-.546**	-.524**	-.545**	.497**
	Sig. (2-tailed)		.	.	.000	.000	.000	.000
	N	48	0	0	48	48	48	48
Zn_1x	Pearson Correlation	.[a]	1	.[a]	-.477**	-.483**	-.484**	.428**
	Sig. (2-tailed)	.		.	.001	.001	.000	.002
	N	0	48	0	48	48	48	48
Zn_2x	Pearson Correlation	.[a]	.[a]	1	-.479**	-.472**	-.478**	.422**
	Sig. (2-tailed)	.	.		.001	.001	.001	.003
	N	0	0	48	48	48	48	48
Chlorophyll_a	Pearson Correlation	-.546**	-.477**	-.479**	1	.946**	.975**	-.897**
	Sig. (2-tailed)	.000	.001	.001		.000	.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_b	Pearson Correlation	-.524**	-.483**	-.472**	.946**	1	.994**	-.971**
	Sig. (2-tailed)	.000	.001	.001	.000		.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_ab	Pearson Correlation	-.545**	-.484**	-.478**	.975**	.994**	1	-.958**
	Sig. (2-tailed)	.000	.000	.001	.000	.000		.000
	N	48	48	48	144	144	144	144
Total_Carotenoids	Pearson Correlation	.497**	.428**	.422**	-.897**	-.971**	-.958**	1
	Sig. (2-tailed)	.000	.002	.003	.000	.000	.000	
	N	48	48	48	144	144	144	144

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.02 level (2-tailed).

Table D-12. Chlorophyll Correlation with Boron (B) at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL.

Correlations

		B_C	B_1x	B_2x	Chlorophyll_a	Chlorophyll_b	Chlorophyll_ab	Total_Carotenoids
B_C	Pearson Correlation	1	.[a]	.[a]	.345*	.326*	.333*	-.039
	Sig. (2-tailed)		.	.	.016	.024	.021	.790
	N	48	0	0	48	48	48	48
B_1x	Pearson Correlation	.[a]	1	.[a]	.412**	.358*	.376**	-.084
	Sig. (2-tailed)	.		.	.004	.012	.008	.572
	N	0	48	0	48	48	48	48
B_2x	Pearson Correlation	.[a]	.[a]	1	.141	.152	.149	.041
	Sig. (2-tailed)	.	.		.339	.303	.313	.783
	N	0	0	48	48	48	48	48
Chlorophyll_a	Pearson Correlation	.345*	.412**	.141	1	.983**	.992**	-.757**
	Sig. (2-tailed)	.016	.004	.339		.000	.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_b	Pearson Correlation	.326*	.358*	.152	.983**	1	.998**	-.799**
	Sig. (2-tailed)	.024	.012	.303	.000		.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_ab	Pearson Correlation	.333*	.376**	.149	.992**	.998**	1	-.788**
	Sig. (2-tailed)	.021	.008	.313	.000	.000		.000
	N	48	48	48	144	144	144	144
Total_Carotenoids	Pearson Correlation	-.039	-.084	.041	-.757**	-.799**	-.788**	1
	Sig. (2-tailed)	.790	.572	.783	.000	.000	.000	
	N	48	48	48	144	144	144	144

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D-13. Chlorophyll Correlation with Calcium (Ca) at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL.

Correlations

		Ca_C	Ca_1x	Ca_2x	Chlorophyll_a	Chlorophyll_b	Chlorophyll_ab	Total_Carotenoids
	Pearson Correlation	1	.[a]	.[a]	-.335*	-.298*	-.310*	.143
Ca_C	Sig. (2-tailed)		.	.	.020	.040	.032	.334
	N	48	0	0	48	48	48	48
	Pearson Correlation	.[a]	1	.[a]	-.499**	-.441**	-.461**	.423**
Ca_1x	Sig. (2-tailed)	.		.	.000	.002	.001	.003
	N	0	48	0	48	48	48	48
	Pearson Correlation	.[a]	.[a]	1	-.507**	-.451**	-.473**	.224
Ca_2x	Sig. (2-tailed)	.	.		.000	.001	.001	.125
	N	0	0	48	48	48	48	48
	Pearson Correlation	-.335*	-.499**	-.507**	1	.983**	.992**	-.757**
Chlorophyll_a	Sig. (2-tailed)	.020	.000	.000		.000	.000	.000
	N	48	48	48	144	144	144	144
	Pearson Correlation	-.298*	-.441**	-.451**	.983**	1	.998**	-.799**
Chlorophyll_b	Sig. (2-tailed)	.040	.002	.001	.000		.000	.000
	N	48	48	48	144	144	144	144
	Pearson Correlation	-.310*	-.461**	-.473**	.992**	.998**	1	-.788**
Chlorophyll_ab	Sig. (2-tailed)	.032	.001	.001	.000	.000		.000
	N	48	48	48	144	144	144	144
	Pearson Correlation	.143	.423**	.224	-.757**	-.799**	-.788**	1
Total_Carotenoids	Sig. (2-tailed)	.334	.003	.125	.000	.000	.000	
	N	48	48	48	144	144	144	144

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D-14. Chlorophyll Correlation with Copper (Cu) at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL.

Correlations

		Cu_C	Cu_1x	Cu_2x	Chlorophyll_a	Chlorophyll_b	Chlorophyll_ab	Total_Carotenoids
Cu_C	Pearson Correlation	1	.[a]	.[a]	.744**	.729**	.735**	-.644**
	Sig. (2-tailed)		.	.	.000	.000	.000	.000
	N	48	0	0	48	48	48	48
Cu_1x	Pearson Correlation	.[a]	1	.[a]	.681**	.713**	.706**	-.660**
	Sig. (2-tailed)	.		.	.000	.000	.000	.000
	N	0	48	0	48	48	48	48
Cu_2x	Pearson Correlation	.[a]	.[a]	1	.402**	.387**	.394**	-.310*
	Sig. (2-tailed)	.	.		.005	.007	.006	.032
	N	0	0	48	48	48	48	48
Chlorophyll_a	Pearson Correlation	.744**	.681**	.402**	1	.983**	.992**	-.757**
	Sig. (2-tailed)	.000	.000	.005		.000	.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_b	Pearson Correlation	.729**	.713**	.387**	.983**	1	.998**	-.799**
	Sig. (2-tailed)	.000	.000	.007	.000		.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_ab	Pearson Correlation	.735**	.706**	.394**	.992**	.998**	1	-.788**
	Sig. (2-tailed)	.000	.000	.006	.000	.000		.000
	N	48	48	48	144	144	144	144
Total_Carotenoids	Pearson Correlation	-.644**	-.660**	-.310*	-.757**	-.799**	-.788**	1
	Sig. (2-tailed)	.000	.000	.032	.000	.000	.000	
	N	48	48	48	144	144	144	144

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D-15. Chlorophyll Correlation with Iron (Fe) at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL.

Correlations

		Fe_C	Fe_1x	Fe_2x	Chlorophyll_a	Chlorophyll_b	Chlorophyll_ab	Total_Carotenoids
	Pearson Correlation	1	.[a]	.[a]	-.544**	-.508**	-.521**	.230
Fe_C	Sig. (2-tailed)		.	.	.000	.000	.000	.116
	N	48	0	0	48	48	48	48
	Pearson Correlation	.[a]	1	.[a]	-.535**	-.474**	-.495**	.490**
Fe_1x	Sig. (2-tailed)	.		.	.000	.001	.000	.000
	N	0	48	0	48	48	48	48
	Pearson Correlation	.[a]	.[a]	1	-.436**	-.340*	-.376**	.259
Fe_2x	Sig. (2-tailed)	.	.		.002	.018	.008	.076
	N	0	0	48	48	48	48	48
	Pearson Correlation	-.544**	-.535**	-.436**	1	.983**	.992**	-.757**
Chlorophyll_a	Sig. (2-tailed)	.000	.000	.002		.000	.000	.000
	N	48	48	48	144	144	144	144
	Pearson Correlation	-.508**	-.474**	-.340*	.983**	1	.998**	-.799**
Chlorophyll_b	Sig. (2-tailed)	.000	.001	.018	.000		.000	.000
	N	48	48	48	144	144	144	144
	Pearson Correlation	-.521**	-.495**	-.376**	.992**	.998**	1	-.788**
Chlorophyll_ab	Sig. (2-tailed)	.000	.000	.008	.000	.000		.000
	N	48	48	48	144	144	144	144
	Pearson Correlation	.230	.490**	.259	-.757**	-.799**	-.788**	1
Total_Carotenoids	Sig. (2-tailed)	.116	.000	.076	.000	.000	.000	
	N	48	48	48	144	144	144	144

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D-16. Chlorophyll Correlation with Potassium (K) at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL.

Correlations

		K_C	K_1x	K_2x	Chlorophyll_a	Chlorophyll_b	Chlorophyll_ab	Total_Carotenoids
K_C	Pearson Correlation	1	.[a]	.[a]	.447[**]	.409[**]	.422[**]	-.14 0
	Sig. (2-tailed)		.	.	.001	.004	.003	.34 3
	N	48	0	0	48	48	48	48
K_1x	Pearson Correlation	.[a]	1	.[a]	.689[**]	.629[**]	.650[**]	-.375[**]
	Sig. (2-tailed)	.		.	.000	.000	.000	.009
	N	0	48	0	48	48	48	48
K_2x	Pearson Correlation	.[a]	.[a]	1	.179	.118	.140	.120
	Sig. (2-tailed)	.	.		.224	.426	.343	.416
	N	0	0	48	48	48	48	48
Chlorophyll_a	Pearson Correlation	.447[**]	.689[**]	.179	1	.983[**]	.992[**]	-.757[**]
	Sig. (2-tailed)	.001	.000	.224		.000	.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_b	Pearson Correlation	.409[**]	.629[**]	.118	.983[**]	1	.998[**]	-.799[**]
	Sig. (2-tailed)	.004	.000	.426	.000		.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_ab	Pearson Correlation	.422[**]	.650[**]	.140	.992[**]	.998[**]	1	-.788[**]
	Sig. (2-tailed)	.003	.000	.343	.000	.000		.000
	N	48	48	48	144	144	144	144
Total_Carotenoids	Pearson Correlation	-.140	-.375[**]	.120	-.757[**]	-.799[**]	-.788[**]	1
	Sig. (2-tailed)	.343	.009	.416	.000	.000	.000	
	N	48	48	48	144	144	144	144

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D-17. Chlorophyll Correlation with Magnesium (Mg) at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL.

Correlations

		Mg_C	Mg_1x	Mg_2x	Chlorophyll_a	Chlorophyll_b	Chlorophyll_ab	Total_Carotenoids
Mg_C	Pearson Correlation	1	.[a]	.[a]	-.153	-.117	-.129	.024
	Sig. (2-tailed)		.	.	.300	.428	.383	.871
	N	48	0	0	48	48	48	48
Mg_1x	Pearson Correlation	.[a]	1	.[a]	-.407**	-.347*	-.367*	.338*
	Sig. (2-tailed)	.		.	.004	.016	.010	.019
	N	0	48	0	48	48	48	48
Mg_2x	Pearson Correlation	.[a]	.[a]	1	-.374**	-.308*	-.333*	.146
	Sig. (2-tailed)	.	.		.009	.033	.021	.323
	N	0	0	48	48	48	48	48
Chlorophyll_a	Pearson Correlation	-.153	-.407**	-.374**	1	.983**	.992**	-.757**
	Sig. (2-tailed)	.300	.004	.009		.000	.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_b	Pearson Correlation	-.117	-.347*	-.308*	.983**	1	.998**	-.799**
	Sig. (2-tailed)	.428	.016	.033	.000		.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_ab	Pearson Correlation	-.129	-.367*	-.333*	.992**	.998**	1	-.788**
	Sig. (2-tailed)	.383	.010	.021	.000	.000		.000
	N	48	48	48	144	144	144	144
Total_Carotenoids	Pearson Correlation	.024	.338*	.146	-.757**	-.799**	-.788**	1
	Sig. (2-tailed)	.871	.019	.323	.000	.000	.000	
	N	48	48	48	144	144	144	144

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D-18. Chlorophyll Correlation with Manganese (Mn) at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL.

Correlations

		Mn_C	Mn_1x	Mn_2x	Chlorophyll_a	Chlorophyll_b	Chlorophyll_ab	Total_Carotenoids
	Pearson Correlation	1	.[a]	.[a]	-.309*	-.258	-.275	.192
Mn_C	Sig. (2-tailed)		.	.	.033	.077	.059	.191
	N	48	0	0	48	48	48	48
	Pearson Correlation	.[a]	1	.[a]	-.143	-.067	-.091	.140
Mn_1x	Sig. (2-tailed)	.		.	.332	.649	.537	.344
	N	0	48	0	48	48	48	48
	Pearson Correlation	.[a]	.[a]	1	-.230	-.100	-.147	.075
Mn_2x	Sig. (2-tailed)	.	.		.116	.498	.319	.611
	N	0	0	48	48	48	48	48
	Pearson Correlation	-.309*	-.143	-.230	1	.983**	.992**	-.757**
Chlorophyll_a	Sig. (2-tailed)	.033	.332	.116		.000	.000	.000
	N	48	48	48	144	144	144	144
	Pearson Correlation	-.258	-.067	-.100	.983**	1	.998**	-.799**
Chlorophyll_b	Sig. (2-tailed)	.077	.649	.498	.000		.000	.000
	N	48	48	48	144	144	144	144
	Pearson Correlation	-.275	-.091	-.147	.992**	.998**	1	-.788**
Chlorophyll_ab	Sig. (2-tailed)	.059	.537	.319	.000	.000		.000
	N	48	48	48	144	144	144	144
	Pearson Correlation	.192	.140	.075	-.757**	-.799**	-.788**	1
Total_Carotenoids	Sig. (2-tailed)	.191	.344	.611	.000	.000	.000	
	N	48	48	48	144	144	144	144

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table D-19. Chlorophyll Correlation with Sodium (Na) at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL.

Correlations

		Na_C	Na_1x	Na_2x	Chlorophyll_a	Chlorophyll_b	Chlorophyll_ab	Total_Carotenoids
Na_C	Pearson Correlation	1	.[a]	.[a]	-.197	-.193	-.195	.152
	Sig. (2-tailed)		.	.	.179	.188	.184	.302
	N	48	0	0	48	48	48	48
Na_1x	Pearson Correlation	.[a]	1	.[a]	.030	.011	.017	.274
	Sig. (2-tailed)	.		.	.838	.941	.908	.060
	N	0	48	0	48	48	48	48
Na_2x	Pearson Correlation	.[a]	.[a]	1	-.451**	-.427**	-.438**	.536**
	Sig. (2-tailed)	.	.		.001	.002	.002	.000
	N	0	0	48	48	48	48	48
Chlorophyll_a	Pearson Correlation	-.197	.030	-.451**	1	.983**	.992**	-.757**
	Sig. (2-tailed)	.179	.838	.001		.000	.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_b	Pearson Correlation	-.193	.011	-.427**	.983**	1	.998**	-.799**
	Sig. (2-tailed)	.188	.941	.002	.000		.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_ab	Pearson Correlation	-.195	.017	-.438**	.992**	.998**	1	-.788**
	Sig. (2-tailed)	.184	.908	.002	.000	.000		.000
	N	48	48	48	144	144	144	144
Total_Carotenoids	Pearson Correlation	.152	.274	.536**	-.757**	-.799**	-.788**	1
	Sig. (2-tailed)	.302	.060	.000	.000	.000	.000	
	N	48	48	48	144	144	144	144

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D-20. Chlorophyll Correlation with Phosphorus (P) at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL.

Correlations

		P_C	P_1x	P_2x	Chlorophyll_a	Chlorophyll_b	Chlorophyll_ab	Total_Carotenoids
P_C	Pearson Correlation	1	.[a]	.[a]	.583**	.556**	.566**	-.259
	Sig. (2-tailed)		.	.	.000	.000	.000	.075
	N	48	0	0	48	48	48	48
P_1x	Pearson Correlation	.[a]	1	.[a]	-.112	-.108	-.109	-.145
	Sig. (2-tailed)	.		.	.449	.466	.459	.324
	N	0	48	0	48	48	48	48
P_2x	Pearson Correlation	.[a]	.[a]	1	.305*	.267	.282	-.080
	Sig. (2-tailed)	.	.		.035	.066	.052	.590
	N	0	0	48	48	48	48	48
Chlorophyll_a	Pearson Correlation	.583**	-.112	.305*	1	.983**	.992**	-.757**
	Sig. (2-tailed)	.000	.449	.035		.000	.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_b	Pearson Correlation	.556**	-.108	.267	.983**	1	.998**	-.799**
	Sig. (2-tailed)	.000	.466	.066	.000		.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_ab	Pearson Correlation	.566**	-.109	.282	.992**	.998**	1	-.788**
	Sig. (2-tailed)	.000	.459	.052	.000	.000		.000
	N	48	48	48	144	144	144	144
Total_Carotenoids	Pearson Correlation	-.259	-.145	-.080	-.757**	-.799**	-.788**	1
	Sig. (2-tailed)	.075	.324	.590	.000	.000	.000	
	N	48	48	48	144	144	144	144

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table D-21. Chlorophyll Correlation with Sulfur (S) at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL.

Correlations

		S_C	S_1x	S_2x	Chlorophyll_a	Chlorophyll_b	Chlorophyll_ab	Total_Carotenoids
S_C	Pearson Correlation	1	.[a]	.[a]	-.044	-.028	-.033	.048
	Sig. (2-tailed)		.	.	.764	.852	.823	.745
	N	48	0	0	48	48	48	48
S_1x	Pearson Correlation	.[a]	1	.[a]	.746**	.694**	.712**	-.499**
	Sig. (2-tailed)	.		.	.000	.000	.000	.000
	N	0	48	0	48	48	48	48
S_2x	Pearson Correlation	.[a]	.[a]	1	.057	.007	.025	.067
	Sig. (2-tailed)	.	.		.702	.963	.868	.653
	N	0	0	48	48	48	48	48
Chlorophyll_a	Pearson Correlation	-.044	.746**	.057	1	.983**	.992**	-.757**
	Sig. (2-tailed)	.764	.000	.702		.000	.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_b	Pearson Correlation	-.028	.694**	.007	.983**	1	.998**	-.799**
	Sig. (2-tailed)	.852	.000	.963	.000		.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_ab	Pearson Correlation	-.033	.712**	.025	.992**	.998**	1	-.788**
	Sig. (2-tailed)	.823	.000	.868	.000	.000		.000
	N	48	48	48	144	144	144	144
Total_Carotenoids	Pearson Correlation	.048	-.499**	.067	-.757**	-.799**	-.788**	1
	Sig. (2-tailed)	.745	.000	.653	.000	.000	.000	
	N	48	48	48	144	144	144	144

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D-22. Chlorophyll Correlation with Zinc (Zn) at Lauritsen/Wohler's Outdoor Golf Practice Facility, Urbana, IL.

Correlations

		Zn_C	Zn_1x	Zn_2x	Chlorophyll_a	Chlorophyll_b	Chlorophyll_ab	Total_Carotenoids
Zn_C	Pearson Correlation	1	.[a]	.[a]	.017	-.012	-.003	.033
	Sig. (2-tailed)		.	.	.910	.935	.985	.822
	N	48	0	0	48	48	48	48
Zn_1x	Pearson Correlation	.[a]	1	.[a]	.401**	.339*	.360*	-.105
	Sig. (2-tailed)	.		.	.005	.018	.012	.479
	N	0	48	0	48	48	48	48
Zn_2x	Pearson Correlation	.[a]	.[a]	1	.014	-.019	-.007	.076
	Sig. (2-tailed)	.	.		.924	.899	.962	.610
	N	0	0	48	48	48	48	48
Chlorophyll_a	Pearson Correlation	.017	.401**	.014	1	.983**	.992**	-.757**
	Sig. (2-tailed)	.910	.005	.924		.000	.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_b	Pearson Correlation	-.012	.339*	-.019	.983**	1	.998**	-.799**
	Sig. (2-tailed)	.935	.018	.899	.000		.000	.000
	N	48	48	48	144	144	144	144
Chlorophyll_ab	Pearson Correlation	-.003	.360*	-.007	.992**	.998**	1	-.788**
	Sig. (2-tailed)	.985	.012	.962	.000	.000		.000
	N	48	48	48	144	144	144	144
Total_Carotenoids	Pearson Correlation	.033	-.105	.076	-.757**	-.799**	-.788**	1
	Sig. (2-tailed)	.822	.479	.610	.000	.000	.000	
	N	48	48	48	144	144	144	144

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).