Evaluating the Effects of Various Painting Techniques on Athletic Field Surface and Root Zone Characteristics

A Thesis Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Bryan McKinley Ogle

May 2020

DEDICATION

To my parents, Linda and Lowell Richey, for their support, love, and guidance throughout my life. I am very bless to have them in my life.

To my wife, Heather, thank you so much for always being there for me. You have encouraged me and always believed in me.

ACKNOWLEDGEMENTS

I would like to thank my committee members: Dr. John Sorochan, Dr. Thomas Samples, and Dr. Brandon Horvath for their leadership, expertise, and support throughout all stages of my graduate degree at the University of Tennessee. Special thanks to Dr. John Sorochan for allowing me to pursue my Graduate degree, for pushing me, and helping me with my career in turfgrass.

I would also like to thank the University of Tennessee Athletic Department for allowing me to obtain my graduate degree while being employed. The knowledge and findings of my graduate studies have turned our turfgrass fields into one of the premier playing surfaces in the country. I will always bleed orange and hold this university dear to my heart. GO VOLS!

Thank you to all of the current and past assistants in the plant sciences department, Adam Thoms, Kyley Dickson, Dan Strunk, and Taylor Williams. Without their help, there is absolutely no way I could have managed all of the work that went into making my research possible.

I would also like to thank Pioneer Athletics for providing supplies and information for this research. Doug Schattinger and Chris Fiore were more than helpful on the initial planning of this research.

ABSTRACT

Every year, thousands of sports turf managers on natural apply athletic field marking paint. Research was conducted comparing different treatments consisting of various nozzle sizes and pressure settings for applying athletic field paint. Objectives of this research is to provide sports turf managers information on nozzle size and pressure setting of painting equipment to reduce the negative effects of athletic turf paint on soil root zones. Treatment applications simulated an NCAA football schedule in 2015, 2016, and 2019 to ‘Tifway 419’ (*Cynodon dactylon* (L.) Pers. x *Cynodon transvaalensis*, Burtt-Davy) bermudagrass sod established in 2011 and maintained on a USGA sand-based root zone (United States Golf Association, 2018). Soil samples from each treatment area were subjected to analysis of variance (ANOVA) consisting of porosity, bulk density, and percent organic matter. Measurements of each treatment determined the quantity of paint sprayed from the different nozzles and pressure settings. Based on the quantity of each treatment cost analysis determined the cost of each treatment. Turf Analyzer, a computer software program, evaluated digital images of each paint treatment to determine differences in color uniformity and brightness. No significant differences were detected in the soil analysis. However, in cost analysis discovered substantial differences in treatment cost to paint basic football field markings. Calibration of treatments discovered up to 312% difference in quantity of paint applied between small nozzle with lower pressure compared to larger nozzle and high pressure. Digital image analysis determined a significant difference of percent brightness of athletic turf paint in the nozzle size x pressure setting interaction. However, visual quality assessment could not detect difference. Information in this study will provide sports turf managers cost effective parameters while still obtaining visually appealing paint applications.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I – EVALUATING THE EFFECTS OF VARIOUS PAINTING TECHNIQUES ON ATHLETIC FIELD ROOT ZONE CHARACTERISTICS

Abstract

Minimal information regarding paint machine settings to limit the negative effects of multiple paint applications on the same root zone areas have been provided to sports turf managers. Research was conducted to compare different treatments consisting of various nozzle sizes and pressure settings for applying athletic turf paint. The objective of this research is to identify those that allow the best paint coverage with the least amount of detrimental effects on the root zone. Applications occurred eight times, simulating an NCAA football schedule. Paint treatments applied in 2015 and 2016 to 'Tifway 419' Bermudagrass sod maintained on a sand-based root zone. Soil samples from each treatment area were subject to analysis consisting of porosity, bulk density, and percent organic matter. Soil sample findings were subjected to analysis of variance (ANOVA) using the statistical program SAS (version 9.3; SAS Institution Inc.) to determine treatment effects. The quantity of paint sprayed from each treatment using the different nozzles and pressure settings was calculated. A cost analysis was performed to verify each treatment cost. A visual analysis was also conducted to evaluate paint treatments. No scientific differences could be determined between treatments from soil analysis or visual assessment. Calibration of each treatment resulted in up to a 63% increase in amount of paint applied in treatments. Cost analysis reported up to a 312% difference in treatments.

Introduction

Sports turf managers play a vital role in preparing a safe and visually appealing playing surface for natural turfgrass athletic fields. In addition to the upkeep of the playing surface, they layout stencils and apply athletic field paint to produce required markings. Different sports require numerous boundaries and markers in order for games to be played (Puhallatab et al., 2010). The minimum required white markings for a NCAA college football field, for example, consist of 223m^2. However, turf managers also reproduce team logos and other symbols on the field to enhance the game-day experience. When these managers paint large end zone logos, mid-field logos, decorative boarders, and other special symbols, the area in which athletic field paint is applied can quickly increase to 1100-1300m^2. This larger amount of painted area often covers 15-20% of the playing surface and requires multiple paint applications throughout the season.

When routinely applied, athletic field paint used to create the markings and logos, will damage turfgrass by limiting photosynthesis (Reynolds et al., 2015). Photosynthesis is slowed by athletic field paint as a result of a reduction in photosynthetically active radiation (PAR) the plant leaf absorbs when paint is applied to the surface (Reynolds et al., 2012). In addition to PAR, the total canopy photosysnthesis (TCP) is reduced after multiple paint applications (Reynolds et al., 2012).

When athletic turf paint is regularly applied along with common cultral practices such as aerfiying and sand topdressing, layers of paint in the soil profile have been found in the root zone. Many athletic field root zones are constructed on native soils; however, sand-based root zones using USGA specifications for constructing has expanded to the building of athletic fields for collegiate and professional sports (Bigelow and Soldat, 2013). A sand-based turfgrass root zone usually delivers a high water infiltration rate and improved compaction resistance (Brockhoff et al., 2010). Athletic turf paint applied on sand based root zones found painted sand particles bind together creating larger particle size percentages in the soil particle size analysis (May, 2019).

Athletic turf paint concentrate ingredients are acrylic latex, calcined kaolin, and titanium dioxide (Pioneer Athletics, Cleveland, OH). The turf paint concentrate is mixed with water in order to dilute the mixture to be able to spray, in adddition act as a solvent in the mixture. The spraying process consists of the paint mixture emerging from a fan nozzle orifice as a sheet which rapily atomizes the paint into fine droplets (Xing et al., 1997). Using this technique allows rapid coverage of the coating to the substrate (Xing et al., 1997). Specialized paint machines capable of spraying of high viscosity fluids, such as athletic turf paint, must have a nozzle to apply paint. Changing the nozzle opening, also known as orfice, determines the film thickness of the paint being applied (Xing et al., 1997). With multiple nozzle sizes available on the market, discovering combinations of nozzle size along with pressure setting would minimize any negative effects of repeated applications of athletic field paint on the root zone. Thus, the objective of this research is to examine various sized paint nozzles and pressure settings and to identify those that allow for the best paint coverage with the least amount of detrimental effects on the root zone.

Materials and Methods

A field experiment was conducted based on the University of Tennessee football schedule in both 2015 and 2016 seasons at the University of Tennessee, Knoxville, TN. Treatments were selected upon review of a nationwide survey of athletic field managers regarding nozzle tips and pressures being used to apply paint (Table 1), (all tables referenced are displayed in the appendix section at the end of this document). The hypothesis is that a substantial application of paint using high pressure and larger nozzles will negatively affect the performance of the sand-based root zone.

Beginning 5 September 2015, treatments were applied once per wk., totaling eight applications, throughout a 13-wk. period mimicking a collegiate football home-game schedule (Table 2). This application schedule simulates sports turf managers applying paint in preparation for eight home football games. Treatments were applied to ‘Tifway’ (*Cynodon dactylon* (L.) Pers. x *Cynodon transvaalensis*, Burtt-Davy) bermudagrass sod established in 2011 and maintained on a USGA sand-based root zone (United States Golf Association, 2018). Treatments were replicated in 2016 beginning on 30 August 2016 (Table 2). Treatments were applied in different locations each year. Plots were overseeded with a perennial ryegrass (*Lolium prenne* L.) blend, containing 39.55% ‘Sideways’ (PSRX-S84), 30.74% ‘SR 4650’ (PSRX-3701), and 28.19 % ‘Harrier’ (SRX -4UP3), on 5 November, 2015 and 9 November, 2016 at the rate of 19 kg ha^{-1}, to simulate current practices on college football fields.

The experimental design of the study was a randomized complete block using a factorial analysis with three replications. The eighteen sample plots (experimental units) were 0.91m x 0.91m in size, with a 0.3m buffer zone on the perimeter of individual plots (Figure 1), (all figures referenced are displayed in the appendix section at the end of this document). The buffer zone ensured that paint remained inside the treatment areas, preventing horizontal, below ground migration, and cross contamination (Figure 2). A Pioneer Brite Striper 3000 paint machine (Pioneer Athletics, Cleveland, OH) was loaded with Pioneer Brite Stripe white paint (Pioneer Athletics, Cleveland, OH) mixed at a 1:1 paint and water ratio (Figure 1). Factors consisted of two nozzle types (Graco RAC 5 nozzle - 319 size and Graco RAC 5 nozzle - 431 size), and three paint application pressures; 500 pounds per square inch (psi), 1000 psi, and 1500 psi, respectively (Table 1). The paint gun average nozzle height was 0.3m from the surface and held parallel to the ground. Spraying was conducted, inside a wooden stencil, using a 50% fan overlap with a vertical pattern and a horizontal pattern to ensure the turfgrass blades were evenly coated.

After plots were painted and cured for 24 hrs, a visual quality rating was recorded for each treatment area. Cure is referred to as all water solvent has been evaporated, leaving the turfgrass leaf blades coated with pigment and hard to the touch. The visual quality rating was based on amount of green leaf tissue visible after paint treatments were applied. Each treatment area was evaluated based on a 1-6 scale, with 6 representing no visual green leaf tissue visible to the human eye. A rating of 1 indicated that green leaf tissue was visible in more than one-half of the treatment area. Visual quality ratings of each plot were recorded for both years of the study.

Two root zone sub-samples were extracted from each plot before the study was initiated to establish baseline values. Upon completion of the eight applications of paint, two root zone samples were collected from each experimental unit for comparison to pre-treatment values (Figure 3). Root zone samples were taken using a 5cm x 5cm metal tube similar to one described by Uhland (1950) in order to determine soil physical properties. The metal tubes were driven into the ground and soil cores were extracted. As the cores were removed from the root zone, excess soil was removed from the bottom of the sample and cheesecloth was immediately used to cover the bottom of every sub-sample (Flint and Flint, 2002). Each cheesecloth was attached using a rubber band wrapped around the metal tube. Physical analysis was conducted on each root zone core, including soil bulk density using similar methods described by Grossman and Reinsch (2002). Air-filled macro pore space was determined by placing samples into a desiccator for 48 hrs (Flint and Flint, 2002). Capillary porosity and micro pore space was determined by placing samples into a pressure plate extractor and drying for 24 hrs at 2 kPa (kilopascal) (Flint and Flint, 2002). Organic matter content was determined by grinding each sample and placing it inside a 400°C muffle furnace for 48 hrs (Flint and Flint, 2002). The organic matter content was calculated as the difference in weight in grams before and after samples was placed in a muffle furnace.

Soil sample data were subjected to an analysis of variance (ANOVA) using the statistical program SAS (Version 9.3; SAS Institute Inc.) to determine treatment effects. The SAS program was instructed to use treatments with the factors nozzle size, pressure setting, and the interaction between nozzle size and pressure setting to identify significant differences at the $p<0.05$ probability level.

Each treatment was calibrated to determine the specific quantity of athletic turf paint, in milliliters, dispensed during each treatment application. A Pioneer Brite Striper 3000 paint machine (Pioneer Athletics) was loaded with Pioneer Brite Stripe white paint (Pioneer Athletics) mixed at a 1:1 paint to water ratio. The paint sprayer was fitted with two different Graco nozzles (Graco RAC 5 nozzle - 319 size and Graco RAC 5 nozzle - 431 size). Paint was sprayed through the nozzles at each of the three pressures: 500 psi, 1000 psi, and 1500 psi, respectively and collected in a 5-gallon catch can (Figure 4). This procedure was replicated three times. The amount of paint applied in each replication was measured in a 4000-Milliliter (ml) measuring pitcher and recorded (Figure 5). The average of the three replications was recorded (Figure 6).

Lastly, each treatment was subjected to a cost analysis using $80 per concentrated bucket of Pioneer Bright Stripe white paint (Pioneer Athletics). Cost per bucket was determined using a 1:1 paint and water ratio. The basic white marking area required by the NCAA for a football field was determined to be 223 m^2. Quantity of paint per treatment was determined and multiplied by cost per bucket to paint required markings (Figure 7). In addition, cost analysis was calculated simulating eight home games per season (Figure 8).

Results and Discussion

No differences among individual treatments were observed for visual turf quality (Table 3). After each application of paint, none of the plots illustrated any noticeable quantity of green leaf tissue visible to the naked eye. Each treatment exhibited good coverage of the leaf blades after the turf paint cure for 24 hrs (Figure 2). Spraying each treatment area in two different directions could explain the total coverage of the leaf blades in each plot. After treating plots and allowing paint to cure for 24 hrs, no differences in paint coverage could be distinguished.

Similarly, no significant differences in soil micro-porosity, macro-porosity, bulk density or organic matter occurred because of varying nozzle size or application pressure settings in either year of the study (Table 3). Thus, no difference in pressure setting or nozzle size used during this trial negatively affected the soil structure of the sampled areas. As a result, the research results did not facilitate the identification of the best treatment combination to be used by sports turf managers to apply paint to athletic fields. This does not support our hypothesis that routinely painting fields using high pressure and large nozzles will negatively affect the root zone.

Soil micro-porosity varied significantly between years (Table 3). The authors attribute this difference to moving the experimental area from one year to the next. First and second year treatments were performed in plots at different locations.

Volume difference among treatments was determined by measuring the output of each treatment using the two different nozzle sizes and the three variations in pressure when painting a $1m^2$ area (Figure 6). The Graco 319 nozzle has an orifice size of 0.4826 mm compared to the Graco 431 nozzle orifice size of 0.7874 mm. The 319 nozzle has a maximum flow rate of 0.38

gallons per min (gpm), while the 431 nozzle has a maximum flow rate of 1.03 gpm (GRACO INC, Minneapolis, MN). However, the flow rate of the nozzle is dependent on the pressure setting and viscosity of the fluid being used. This difference in orifice size results in a flow increase of 0.65 gpm when spraying with a 431 compared to a 319 nozzle. Treatments 1 and 2 delivered a volume of 470 ml and 769 ml per 1 m^2, respectively (Figure 6). Although the same nozzle was utilized in both Treatments, increasing the pressure setting resulted in a 63% increase in output volume (Figure 6). The increase of paint sprayed resulted from a 500-psi increase of pressure setting on the Pioneer paint machine. Comparing treatment 1 to treatment 3 resulted in a 459 ml increase in amount of paint over the same area, respectively (Figure 6). Therefore, using a Graco 431 nozzle size will almost double the amount of paint sprayed over the same area being painted when compared to a Graco 319 size nozzle.

Sports turf managers often have a set budget to spend annually on the fields they manage. They direct a portion of the yearly budget to purchase and apply paint. Therefore, any increase in amount of athletic turfgrass paint used would result in the need to adjust the budget. The cost of each paint treatment necessary to achieve the minimum required marking of a NCAA football field for one game is presented (Figure 7). Treatment 1 was found to have a calculated cost of $223 when the cost of concentrate equaled $80.50 for a five-gallon quantity for one game. Treatment 2 was found to cost $364 for the same required markings from the NCAA. Sports turf managers are required to paint football fields more than once each season. On average, there are eight home games for teams in the NCAA. A cost analysis was calculated painting the minimum required markings eight times (Figure 8). When comparing all treatments, the cost savings over an entire football season becomes apparent (Figure 8). Treatment 3 cost is nearly double that of

Treatment 1 over eight paint applications (Figure 8). When compared to Treatment 1, Treatment 6 resulted in a 312% cost increase over eight paint applications, respectively. The author suggest that sports turf managers consider Treatment 1 or 2 when the objective is to provide good paint coverage and visual qualities while saving the most money.

CHAPTER II – EVALUATING TURFGRASS PAINTING TECHINQUES WITH DIGITIAL IMAGE ANALYSIS

Abstract

Sports turf managers apply turfgrass paint to athletic field surfaces to create required markings and team logos. They sometimes apply high volumes and multiple coats of paint over several days leading up to game-day to make the field aesthetically pleasing. However, these turfgrass managers are usually applying the quantity of paint based on experience and at his or her own discretion. Therefore, a study was conducted to provide sports turf manager's specific information needed to make informed decisions regarding spraying techniques to deliver an appropriate level of paint coverage within budget. Six turfgrass paint treatments were applied in 2019 to a sand-based plot with bermudagrass. Treatments were applied on 1 October 2019 and 2 December, 2019. Treatments consisted of two nozzle sizes and three pressure settings selected based on responses of sports turf managers to a national survey. Digital images of each plot were uploaded into Turf Analyzer, a java-based computer software capable of determining differences in color uniformity and brightness of paint treatments applied to the turfgrass. It was discovered that that nozzle size x pressure setting interaction was found to be significant. However, that difference was determined to equal 2.8% increase in brightness level. No significant differences were found in paint uniformity or fading between treatments.

Introduction

Research results from the previous field experiment revealed the combination of larger nozzles and higher pressures deliver more paint to the turfgrass surface than the combination of smaller nozzles and lower pressures. While the variety of painting treatments may not produce significant differences in the bermudagrass root zone, sports turf managers' report negative effects such as poor recovery and slower growth during spring transition from winter dormancy following routine, sequential painting the previous fall. More research needs to be conducted to discover the causes of these negative physiological responses. Athletic fields are painted in order to host sporting events. Participants and fans must be able to distinguish required markings and clearly view team logos. As a result, sports turf managers must develop painting protocols that produce vivid markings without applying excessive amounts of paint that restrict plant growth or severely damage turfgrasses. Therefore, the objective of this study is to determine if athletic field paint can be applied in lower volumes while obtaining the high brightness values producing clear and vividly pleasing markings.

A person's perception of color is a highly subjective as a result of not sharing equal amounts of cone photoreceptor pigments in the eye (Kremers, et al. 2016). However, color is one of the major attributes that affect consumer perception of food quality (Francis, 1995). When considering sporting event enthusiasts as consumers of a product, with the product being the turfgrass playing surface, bright uniform colors of paint are preferred.

While sports turf managers are responsible for the painting of the markings, their view of a uniform and vibrant paint marking may not be equivalent to that of the fan sitting in an elevated seat on the field's perimeter. In today's design, stadiums are built more steeply to join spectators and athletes as close as possible (Frank and Steets, 2010). The steepness in design increases sight lines for spectators to view the playing surface without obstruction (Culley and Pascoe, 2005). Therefore, spectators are viewing field markings from steeper view angle and longer distance than sports turf managers. Conversely, sports turf managers, in direct contact with the field, may perceive an imperfection indistinguishable from spectator seating. This could result in an unneeded application of paint to cover a blemish spectators cannot determine.

Traditionally, overall turfgrass quality has been evaluated by using a visual rating scale of 1 to 9, with 9 = ideal turf (Karcher and Richardson, 2003). Although visual color ratings are acquired quickly and with no need for specialized equipment, results are subjective and human bias among turfgrass variety trials is difficult to remove (Karcher and Richardson, 2003). Digital image analysis (DIA) is being used to quantify turfgrass color and stand density with increased precision compared to more traditional methods (Richardson et al., 2001). Using DIA to compare and contrast painted turfgrass surfaces reduces the potential for inconsistencies associated with human, subjective measurements, and limit inconsistencies in data when more than one person evaluates plots (Karcher and Richardson, 2003).

Recently, several turfgrass-based digital image analysis programs have been created. For example, Canepeo, ASSESS (Lamari, 2002), and Turf Analyzer (Karcher et al., 2017) computer software programs were created especially for scientists and turfgrass industry professionals. Canopeo uses color values within the red-green-blue (RGB) spectrum to analyze and classify all color pixels in an image of turfgrass (Patrignani and Ochsner, 2015). ASSESS has been successfully used to estimate disease severity on turfgrass by converting turfgrass image's RGB to Hue, Saturation, and Intensity values to predict disease epidemics (Horvath and Vargas, 2005). Additionally, the Turf Analyzer program evaluates turf images for green coverage and other color-based pixels on user-defined hue, saturation, and brightness thresholds (Karcher et al., 2017). Pixel color is defined by hue, saturation, and intensity and is most often used to separate areas of interest (Bock and Nutter, 2012). Hue is defined as the pure color of the pixel and intensity is defined as the brightness of a color (Bock and Nutter, 2012). Uniformity is defined as how even the painted surface is.

Materials and Methods

A field experiment was conducted in fall 2019 at the University of Tennessee located in Knoxville, TN. Athletic turfgrass paint treatments were replicated from the previous paint experiment conducted in 2015 and 2016 regarding nozzle tip size and pressure settings used to apply athletic turf paint. The objective of the study is to determine if minimal quantities of turfgrass paint can be applied to a turfgrass surface using the optimal nozzle size and pressure setting to obtain visually appealing color brightness and uniformity. Treatments were applied on 1 October 2019 and 2 December 2019. The experimental design of the study was a randomized complete block using a factorial analysis with three replications. The eighteen sample plots (experimental units) were 0.91m x 0.91m in size, with a 0.3 m buffer zone on the perimeter of individual plots (Figure 9). This buffer zone is intended to ensure that paint remained inside the treatment areas, preventing horizontal, below-ground migration and cross contamination (Figure 9). A Pioneer Brite Striper 3000 paint machine (Pioneer Athletics, Cleveland, OH) was loaded with Pioneer Game Day white paint (Pioneer Athletics, Cleveland, OH) mixed at a 1:1 paint and water ratio (Figure 1). Factors consisted of two nozzle types (Graco RAC 5 nozzle - 319 size and Graco RAC 5 nozzle - 431 size), and three paint application pressures; 500 psi, 1000 psi, and 1500 psi, respectively (Table 1). The paint gun was held parallel to the ground and average nozzle height equaled 0.3 m from the surface. Paint was applied, inside a wooden stencil, using a 50% fan overlap with a vertical pattern and a horizontal pattern to ensure the turfgrass blades were evenly coated (Figure 1).

A digital image analysis was performed on each plot after paint was allowed to cure for 24 hrs. Digital images were captured using a Canon PowerShot G12 digital camera (CANON, INC, Tokyo, Japan) mounted on a lightbox (Figure 9). A lightbox with non-reflective coating was used to capture images under uniform illumination. In order to analyze brightness, fading, and uniformity of paint application, a digital image of each treated plot was taken 1, 2, and 5 d after the initial paint application. Images were saved in a JPEG (joint photo-graph experts group, .jpeg) format. Images from each plot were collected using an image size of 640 by 480 pixels and color bit depth of 16.7 million colors. Camera settings include an aperture of f2.8, focal length of 7mm, and shutter speed of 1/25 sec. Digital images were uploaded to a computer to measure differences among samples using Turf Analyzer (Karcher et al., 2017), a java-based computer application. Photos for this study where analyzed by adjusting the hue and saturation for selecting only the white pixels of the image. The threshold tool in the software shows which pixels out of the image are analyzed. Once the white pixels are determined, the pixels selected are analyzed. The threshold then omits all other colors for detailed analysis of the white pixels. Once the white pixels thresholds where established the values where used to analyze all images. The software then provides a detailed analysis of each image. For this experiment, the Turf Analyzer software program was used to discover differences in uniformity and brightness of digital images of the white turf paint applied using two nozzles and three application pressures in an effort to identify the best combinations.

Results and Discussion

When examining average color brightness values, the effect of nozzle size was found significant (Table 4). The Graco 319 nozzle size brightness value equaled 80.64, while the brightness produced by the larger Graco 431 nozzle equaled 82.17 (Table 5). The effect of pressure setting was found significant (Table 4). The pressure setting of 500-psi yielded the lowest brightness values (Table 5). The pressure setting of 1500-psi, recorded the highest brightness value (Table 5).

The interaction of nozzle sizes x pressure settings was significant when analyzing color brightness (Table 3). Color brightness values resulting from Treatment 1 (80.10) and Treatment 2 (80.70) were not significantly different (Figure 10). Treatment 3 and Treatment 4 also produced similar brightness values of 81.13 and 81.40, respectively (Table 5). Treatments 5 and 6 provided the highest brightness values of 82.20 and 82.90, respectively (Table 5). The brightness of athletic turf paint was determined to be dependent on volume of athletic turf paint applied to turfgrass. Therefore, the authors conclude that increase of nozzle size or pressure will result in higher brightness values.

The experiment could not determine any significant difference in paint uniformity among treatments (Table 4). No significant differences were detected in color brightness or uniformity 1, 3, or 5 days following paint application. Athletic turf paint will become less bright after the initial application from several factors including mowing, irrigation cycles, and other cultural practices.

Future research of expanding the number of nozzle sizes and athletic paint application pressures would increase the probability of identifying a specific, ‘best possible’ combination of nozzle size and pressure setting. In addition, incorporating digital image high-speed recording would illustrate the optimal atomization of the athletic field paint coming from the nozzle. Using this technology along with info of nozzle and pressure calibration, in addition to cost analysis would be needed to discover which nozzle and pressure setting sport turf managers should use in order to achieve the best paint coverage along with cost savings.

CHAPTER III – CONCLUSIONS

Prior to this research, sports turf managers applied excessive paint than required, often at a dramatically increased cost. Sports turf managers not utilizing available nozzle sizes or adjusting pressure on machines were applying increased amount of paint. No significant differences in the turfgrass root zone soil physical were discovered after each year of painting. More research is required with athletic turf paint to discover any negative effects on the root zone from repeated applications on the identical areas. The visual quality assessment could not determine any difference among the applied treatments. Cost analysis of treatments discovered prices ranging from $223 to $919 to paint white markings on a NCAA football field for one game. This is a substantial difference in price, considering no differences could be determined in visual quality during the study. However, digital image analysis of treatment effects confirmed higher volumes of paint resulted in higher brightness of paint. Additionally, an increase in nozzle size or pressure setting resulted in higher brightness values. Brightness of athletic turf paint is dependent on the application volume. However, the greatest difference in percent brightness between brightness equaled 2.8%. Methods of analysis utilized in this study could not determine differences in uniformity of applied paint. Results of this experiment recommend that sports turf mangers use combinations, which include nozzles with larger orifice sizes and lower pressure settings or smaller orifice sizes with higher-pressure settings on the paint machine being used. The recommendation, resulting from this research, illustrates that lower quantity of athletic turf paint can be applied without sacrificing brightness or other aesthetic qualities. Lower quantities of paint applied to turfgrass would promote healthier plants as well as reduce cost. Through this research, it is hopeful, that sports turf managers will select nozzle sizes and pressure settings that provide their preferred level of paint brightness along with saving money in their budget.

REFERENCES

Bigelow, C. A., and D.J, Soldat. 2013. Turfgrass root zones: management, construction methods, amendment characterization, and use. J.C. Stier, B.P. Horgan, and S.A. Bonos (ed.) Turfgrass: Biology, Use, and Management, 383-423.

Bock, C. H. and Nutter JR., F. W. 2012. Detection and measurement of plant disease symptoms using visible-wavelength photography and image analysis. Plant Sciences Reviews 2011, 73

Brockhoff, S. R., N. E. Christians, R. H. Killorn, and D. D., Davis. 2010. Physical and mineral-nutrition properties of sand-based turfgrass root zones amended with biochar. Agron J. 102, 6:1627-1631.

Culley, P. and Pascoe, J. 2005. Stadium engineering. London: Thomas Teflord.

Francis, F.J. Quality as influenced by colour, Food Qual. Prefer. 6 (3) (1995)149–155

Flint, L.E. and A.L. Flint. 2002. Porosity. *In* J.H. Dane and G.C. Topp (ed.) Methods of soil analysis. Part 4. Physical methods. SSSA, Madison, WI. p. 241–254.

Frank, S. and Steets, S. 2010. Stadium Worlds: Football, Space, and the Built Environment. 1st ed. London: Routledge, 2010. Print.

Grossman, R.B. and T.G. Reinsch. 2002. Bulk density and linear extensibility. *In* J.H. Dane and G.C. Topp (ed.) Methods of soil analysis. Part 4. Physical methods. SSSA, Madison, WI. p. 201– 228.

Horvath, B. and J. Vargas Jr. 2005. Analysis of dollar spot disease severity using digital image analysis. International Turfgrass Society Research Journal. 10 (Part 1):p.196-201

Karcher D.E., C. Purcell, and M. Richardson, L. Purcell and W. Kenneth. 2017. New Java Program to Rapidly Quantify Several Turfgrass Parameters from Digital Images. CSSA Oral presentation.

Karcher D.E. and Richardson M.D. 2003. Quantifying Turfgrass Color Using Digital Image Analysis. Crop Sci. 43:943-95.
Doi:10.2135/cropsci2003.9430

Kremers J., R.C. Baraas, and J.N. Marshall, 2016. Human Color Vision. Springer International Publishing AG. Cham Switzerland,

Lamari, L. 2002. Assess: image analysis software for plant disease quantification. APS press.

May, R.C., 2019. Evaluation of the Effects of Repeated Applications of Athletic Field Paint to a Sand-based Rootzone. M.S. Thesis. Iowa State, IA

Patrignani, A., and T.E. Ochsner. 2015. Canopeo: A Powerful New Tool for Measuring Fractional Green Canopy Cover. Agronomy Journal 107(6): 2312–2320.

Puhalla, J., J.V. Krans and M. Goatley. 2010. Sports Fields: Design, Construction, and Maintenance 2nd Ed. John Wiley & Sons, Inc. Hoboken, NJ.

Reynolds, W.C., G.L. Miller, and T.W. Rufty. 2012. Athletic field paint impacts light spectral quality and turfgrass photosynthesis. Crop Sci. 52:2375-2384. Doi:10.2135/cropsci2012.01.0059

Reynolds, W.C., G.L. Miller, and T.W. Rufty. 2015. Athletic Field Paint Color Differentially Alters Light Spectral Quality and Bermudagrass Photosynthesis. Crop Sci. 53:2209-2217. Doi: 10.2135/cropsci2013.01.0014

Richardson M.D., D.E. Karcher, and L.C. Purcell. 2001. Quantifying Turfgrass Cover Using Digital Image Analysis. Crop Sci. 41:1884-1888 Doi:10.2135/cropsci2001.1884

Uhland, R.E. 1950. Physical properties of soils as modified by crops and management. Soil Sci. Soc. Am. Proc. 194:361–366.

United States Golf Association. 2018. United States Golf Association recommendations for a method of putting green construction. [Online] Available at: https://www.usga.org/course-care/manage-your-course/greens.html (Accessed 11 February 2020).

Xing, L., E.J. Glass, and R.H., Fernando. 1997. Spray Application of Waterborne Coatings. Technology for Waterborne Coatings. 15:265-295 Doi: 10.1020/bk-1997-0663.ch015

APPENDIX

Table 1. Summary of athletic field paint applications treatments applied to hybrid bermudagrass [‘Tifway’ *Cynodon dactylon* (L.) Pers. x *Cynodon transvaalensis*, Burtt-Davy] turfgrass sample plots weekly at the University of Tennessee, Knoxville, TN

Treatment	Graco Paint Nozzle Size	Pounds Per Square Inch (psi)
1	319	500 psi
2	319	1000 psi
3	319	1500 psi
4	431	500 psi
5	431	1000 psi
6	431	1500 psi

Table 2. Summary of paint application dates for treatments of athletic field paint applications applied to hybrid bermudagrass [‘Tifway’ *Cynodon dactylon* (L.) Pers. x *Cynodon transvaalensis*, Burtt-Davy] turfgrass during 2015 and 2016 at the University of Tennessee, Knoxville, TN

Year	**Treatment Date**							
2015	4 Sep	11 Sep	18 Sep	2 Oct	9 Oct	6 Nov	13 Nov	27 Nov
2016	30 Aug	7 Sep	16 Sep	23 Sep	12 Oct	4 Nov	11 Nov	18 Nov

Figure 1. Pioneer Brite Striper 3000 paint machine loaded with Pioneer Brite Stripe white paint mixed at a 1:1 paint and water ratio. Wooden stencil measuring 0.91 m x 0.91 m in size, with a 0.3 m buffer zone, applied to hybrid bermudagrass [‘Tifway’ *Cynodon dactylon* (L.) Pers. x *Cynodon transvaalensis*, Burtt-Davy] turfgrass, 2015. University of Tennessee, Knoxville, TN.

Figure 2. Finished treatment plots of Pioneer Brite Stripe white paint applied to hybrid bermudagrass ['Tifway' *Cynodon dactylon* (L.) Pers. x *Cynodon transvaalensis*, Burtt-Davy] turfgrass, after paint curing from year one trial of weekly athletic field paint applications, 2015. University of Tennessee, Knoxville, TN.

Figure 3. Example of soil sample extracted from painted treatment areas on USGA sand-based root zone established in 2011, 2015. University of Tennessee, Knoxville, TN.

Figure 4. Calibration of different treatments of athletic field paint using Pioneer Brite Striper 3000 paint machine loaded with Pioneer Brite Stripe white paint mixed at a 1:1 paint and water ratio, 2016. University of Tennessee, Knoxville, TN.

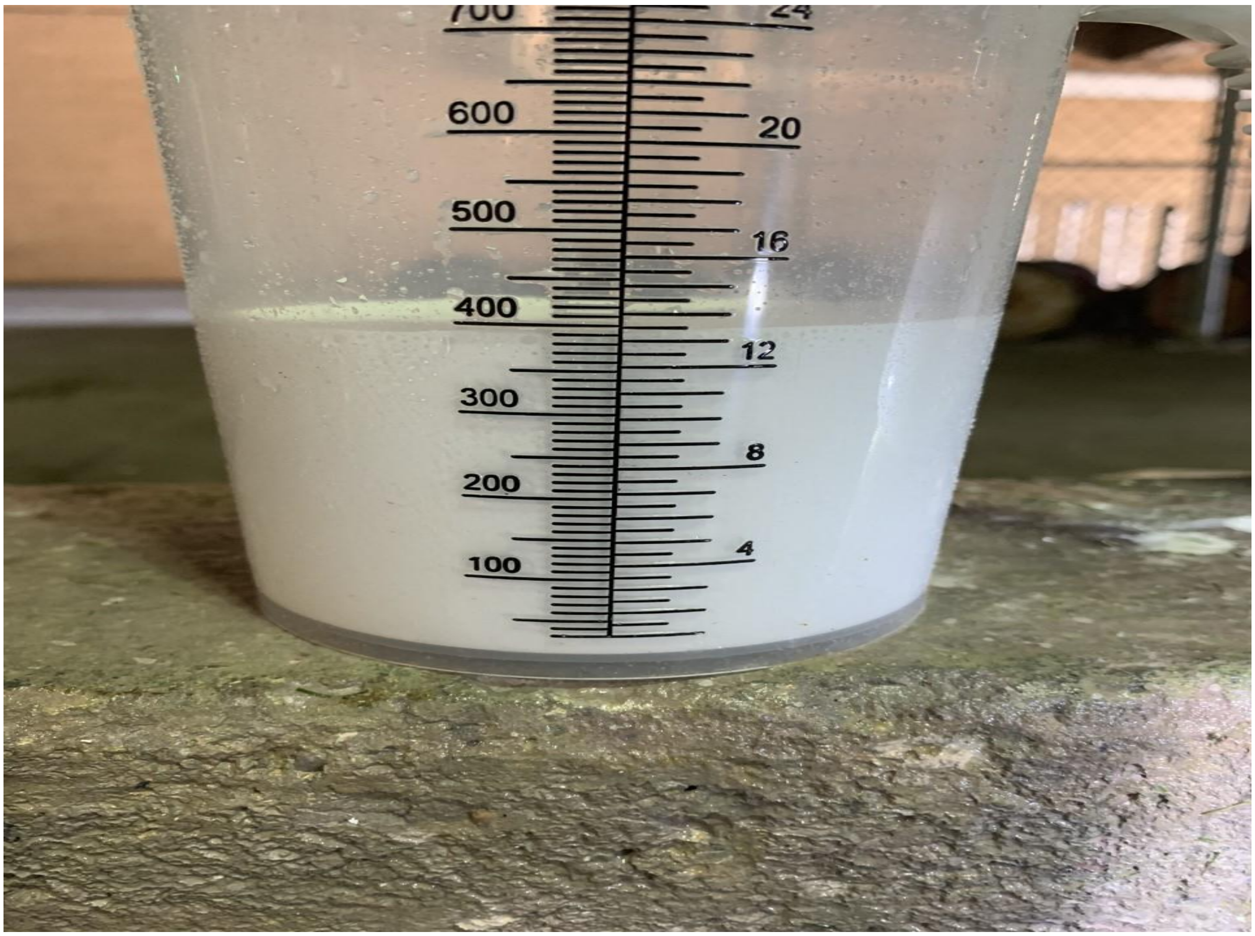

Figure 5. Pioneer Brite Stripe white paint mixed at a 1:1 paint and water ratio being measured using 4000 ml pitcher from calibration process of treatments, 2016. University of Tennessee, Knoxville, TN.

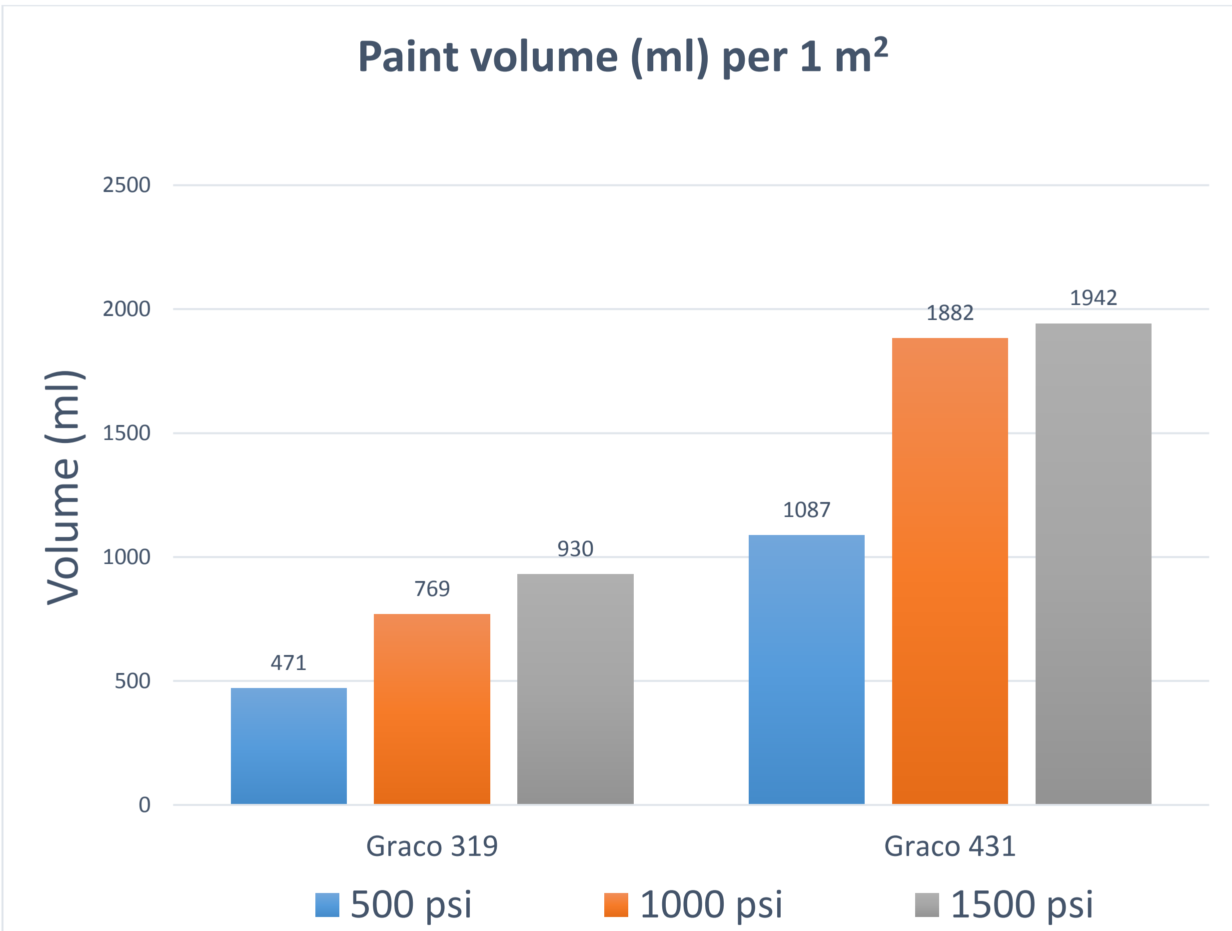

Figure 6. Pioneer Brite Stripe white paint mixed at a 1:1 paint and water ratio measured (ml) for nozzle size (319 and 431) and sprayer pressure (500 psi, 1000 psi, 1500 psi, respectively), 2019. University of Tennessee, Knoxville, TN.

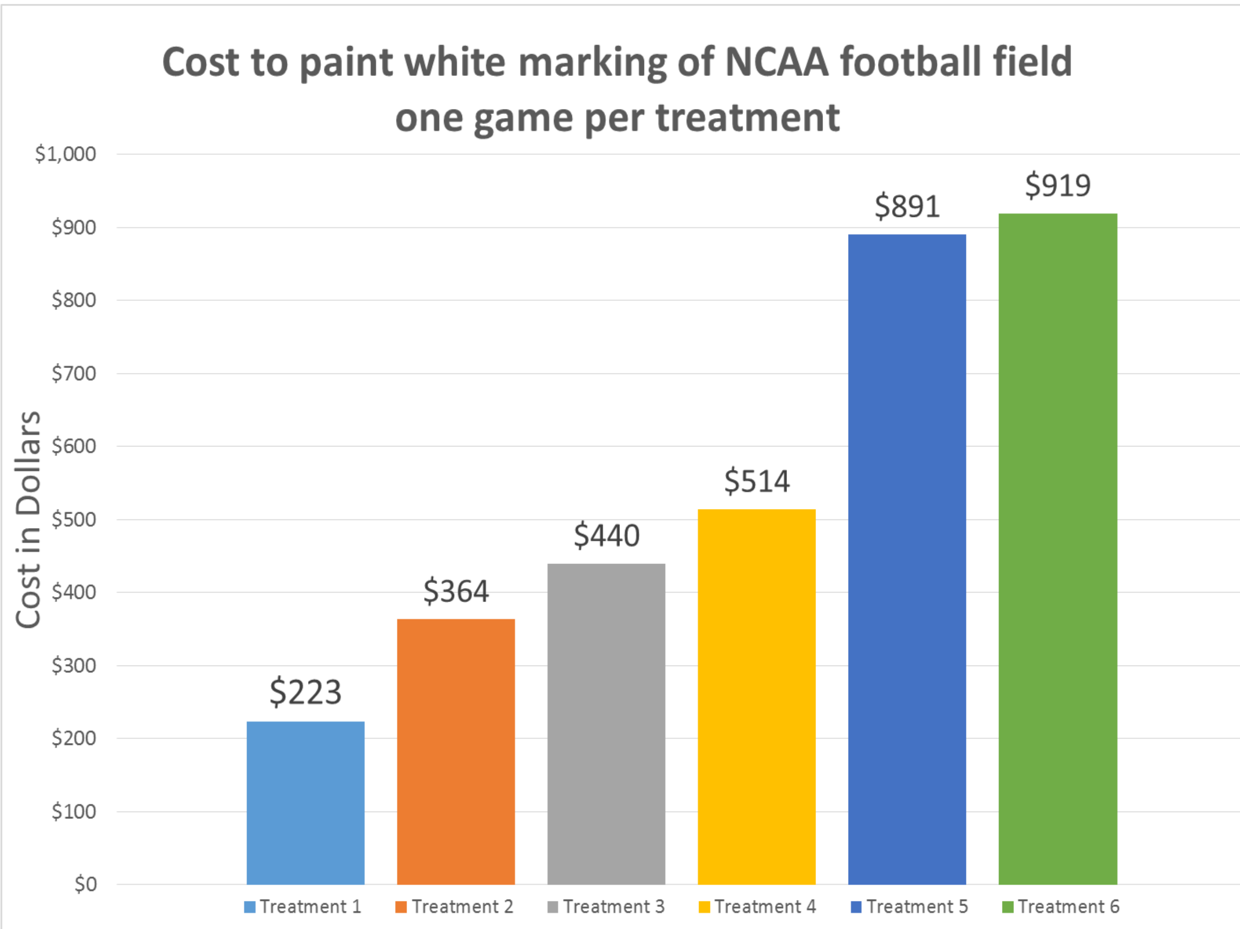

Figure 7. Cost analysis of Pioneer Brite Stripe white paint mixed at a 1:1 paint and water ratio costing $81 per five gallons used to paint basic NCAA football field (566 m^2) using different treatments of nozzle size and pressures per game.

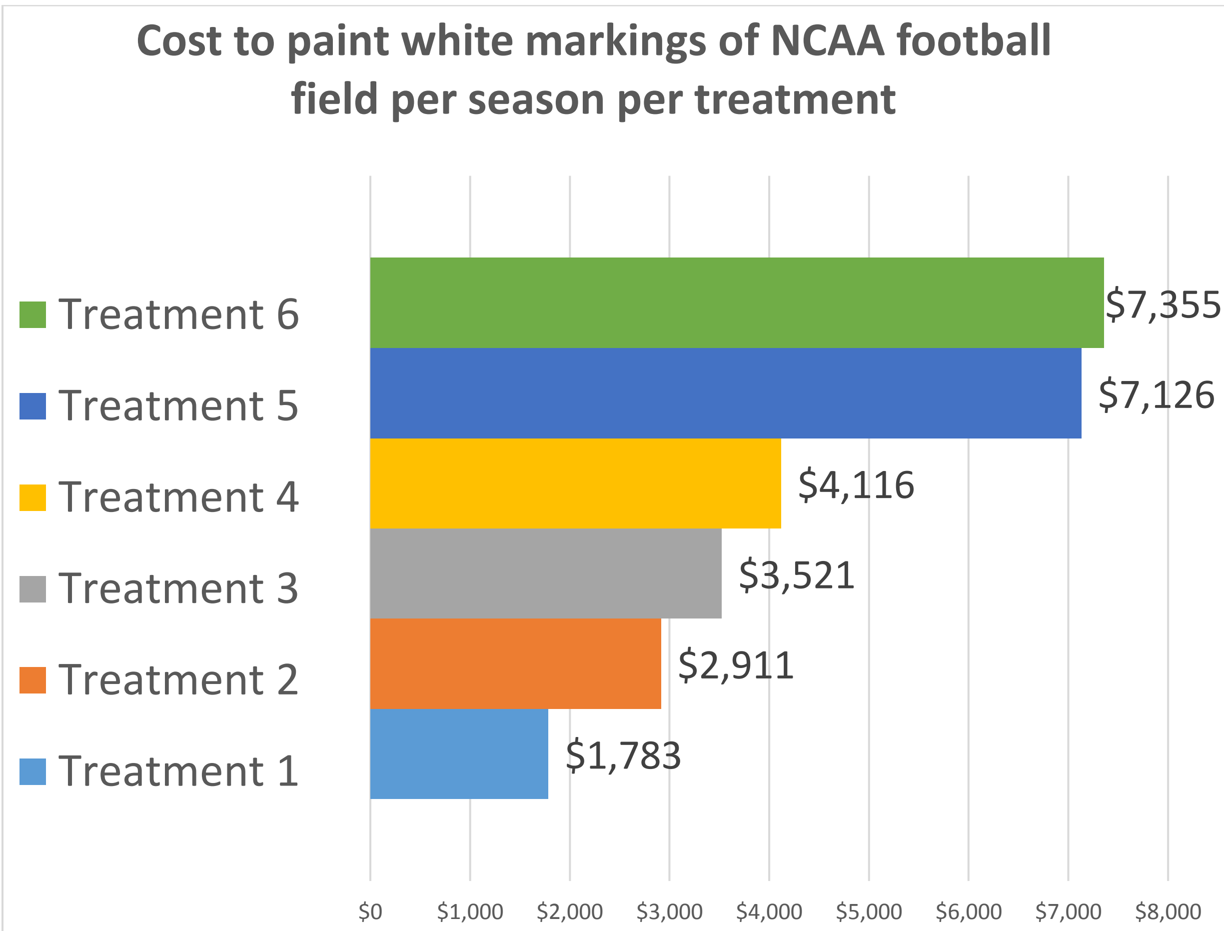

Figure 8. Cost analysis of Pioneer Brite Stripe white paint mixed at a 1:1 paint and water ratio used to paint basic NCAA football field (566 m^2) using different treatments of nozzle size and nozzle pressure over eight game season.

Table 3. Mean squares for athletic field paint treatment effects (nozzle size and sprayer pressure) applied to hybrid bermudagrass [‘Tifway’ *Cynodon dactylon* (L.) Pers. x *Cynodon transvaalensis*, Burtt-Davy] turfgrass, 2015 and 2016. University of Tennessee, Knoxville, TN.

	Micro-porosity	Macro-porosity	Bulk Density	Organic Matter	Percent Green Cover	Visual Quality
Nozzle	NS	NS	NS	NS	NS	NS
Pressure	NS	NS	NS	NS	NS	NS
Nozzle x Pressure	NS	NS	NS	NS	NS	NS
Year	***	NS	NS	NS	NS	NS
Nozzle x Year	NS	NS	NS	NS	NS	NS
Pressure x Year	NS	NS	NS	NS	NS	NS
Nozzle x Pressure x Year	NS	NS	NS	NS	NS	NS

NS - Not Significant at $P \leq 0.05$.
***** - Significant at $P \leq 0.05$.**
Nozzle - Graco nozzle size 319 or 431
Pressure -pressures were 500 psi, 1000 psi, 1500 psi
Years - 2015, 2016

Table 4. Mean squares for athletic field paint treatment effects (nozzle size and sprayer pressure) for digital image analysis of paint applied to hybrid bermudagrass [‘Tifway’ *Cynodon dactylon* (L.) Pers. x *Cynodon transvaalensis*, Burtt-Davy] turfgrass, 2019. University of Tennessee, Knoxville, TN.

	Brightness	Uniformity
Nozzle	***	NS
Pressure	***	NS
Nozzle x Pressure	***	NS
Year	NS	NS
Nozzle x Year	NS	NS
Pressure x Year	NS	NS
Nozzle x Pressure x Year	NS	NS

NS - Not Significant at P ≤ 0.05.
***** - Significant at P ≤ 0.05.**
Nozzle - Graco nozzle size 319 or 431
Pressure -pressures were 500 psi, 1000 psi, 1500 psi
Years - 2015, 2016

Figure 9. Illustration of digital image analysis photograph capturing using the light box on different athletic field paint treatment areas, 2019. University of Tennessee, Knoxville, TN.

Table 5. Average brightness values (percent) of paint treatments of Pioneer Brite Stripe white paint mixed at a 1:1 paint and water ratio white paint treatments applied to hybrid bermudagrass [‘Tifway’ *Cynodon dactylon* (L.) Pers. x *Cynodon transvaalensis*, Burtt-Davy] turfgrass using Turf Analyzer digital image analysis software.

Treatment	Average Brightness Value
Treatment 1	80.10
Treatment 2	80.70
Treatment 3	81.13
Treatment 4	81.40
Treatment 5	82.20
Treatment 6	82.90
Graco 319 Nozzle	80.64
Graco 431 Nozzle	82.17
500 psi	80.75
1000 psi	81.45
1500 psi	82.02

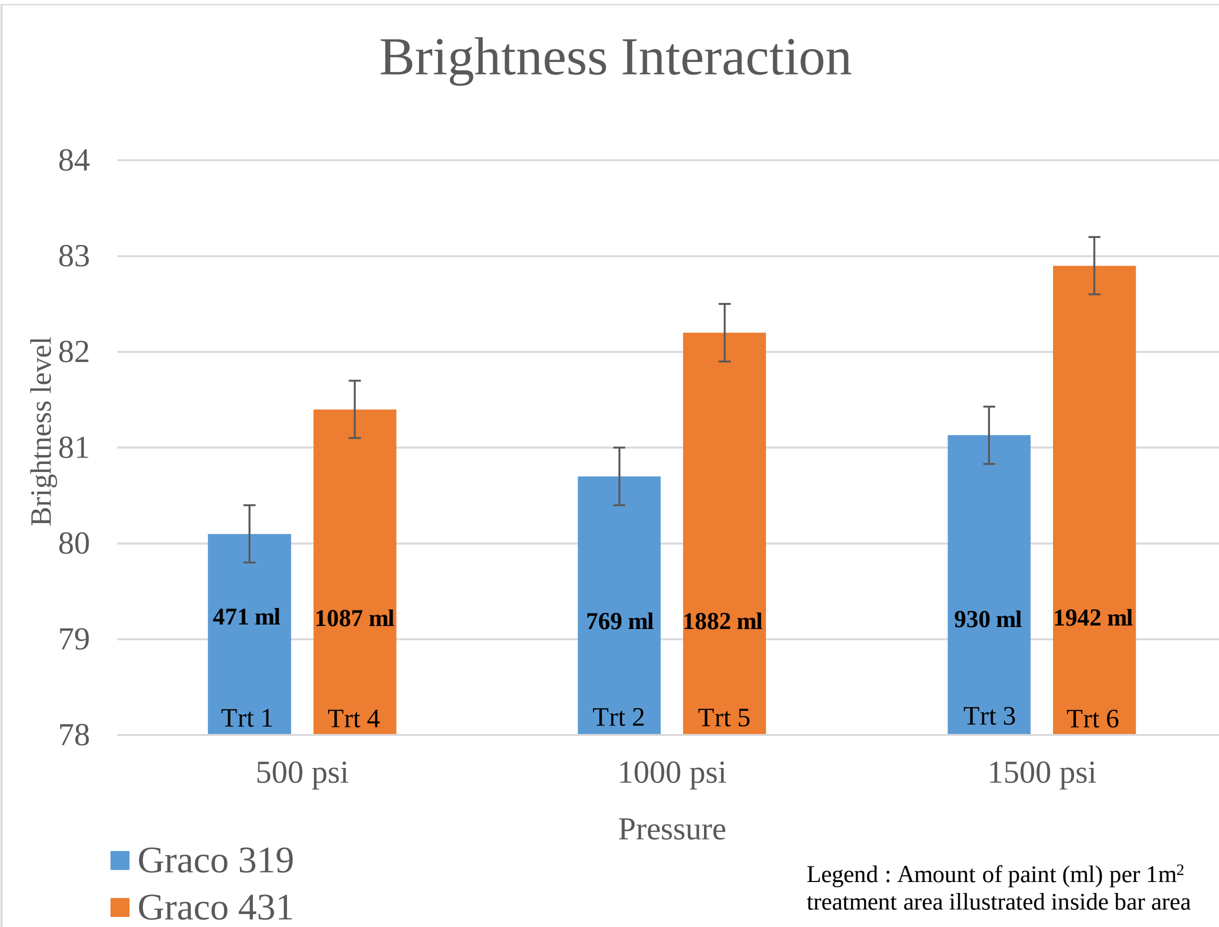

Figure 10. Digital image analysis brightness interaction with standard error bars pooled for nozzle size by pressure setting for white paint treatments applied to hybrid bermudagrass [‘Tifway’ *Cynodon dactylon* (L.) Pers. x *Cynodon transvaalensis*, Burtt-Davy] turfgrass, 2019. University of Tennessee, Knoxville, TN.

VITA

Bryan McKinley Ogle was born on March 4th, 1987 in Knoxville, TN. Bryan was raised by grandparents Linda and Lowell Richey. Bryan has a younger sister Tabatha and wife Heather. Bryan graduated in 2005 from South-Doyle High School in Knoxville, TN. Bryan began working for the University of Tennessee Athletics' as a summer job in 2003 for Sport Surface Management. He continued working for the University of Tennessee Athletics' while attending college as an undergraduate at Walter-State Community College for two years before transferring to the University of Tennessee in Knoxville. Bryan studied Forestry Wildland Recreation in hopes of becoming a National Park Service Ranger. Bryan obtained a bachelor's degree in Forestry in Spring 2010. Bryan then attended South-Western Community College in Franklin, North Carolina, in the fall of 2010, completing National Park Service Seasonal Law Enforcement Training (SLET). However, unsuccessful in obtaining a full-time employment with the National Park Service, Bryan resumed working at the University of Tennessee Athletics' Sport Surface Management. He was hired full-time as a Craft Specialist III in April 2013. Bryan is responsible for maintaining Shield Watkins Field and Haslam Practice fields at the University of Tennessee, Knoxville. In 2015, Bryan decided to continue his academic career by pursuing a master's degree at the University of Tennessee studying Turfgrass management. Bryan was promoted to Ground Crew Leader – Supervisor III in the spring of 2017. He will graduate with this master's degree in the spring of 2020, after which, he will continue overseeing Shield-Watkins field at the University of Tennessee.