ABSTRACT

Title of Thesis:	UNDERSTANDING ORGANIC AND CONVENTIONAL MANAGEMENT PROGRAMS AND RHIZOSPHERE MICROBIOME FOR SPORTS TURF IN MARYLAND
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In response to public concerns about exposure to pesticides, some state and local municipalities have placed restrictions on the use of pesticides on athletic fields. When such restrictions are implemented athletic field management often transitions to the use of natural or organic turf care with little understanding of how the transition away from conventional management practices may affect surface conditions and soil microbial properties.

This thesis examined the use of organic and conventional management programs on the turf quality, surface hardness, and shear strength of engineered soil cap, hybrid bermudagrass (*Cynodon dactylon x Cynodon transvaalensis*) athletic fields, as well as the impact of the two programs on the rhizosphere microbiome. Turf quality was assessed by visual means and by obtaining normalized difference vegetative index (NDVI) readings of the turf canopy. Surface hardness was determined using a Clegg impact surface tester. The rotational shear strength of the surface was measured using a shear vane. The study was conducted for 3 years at two

different locations; research plots at the University of Maryland Research Facility and on athletic fields at Laytonia Recreational Park, in Gaithersburg, MD. Surface property data was collected monthly.

Turf visual quality and NDVI data revealed use of the organic management program led to higher visual quality during spring, which was primarily the result of the spring retention of fall overseeded intermediate ryegrass (*Lolium x hybridum* Hausskn) and early season use of natural based fertilizers. In the summer months, crabgrass (*Digitaria ischaemum* Schreb.) encroachment was limited to the organically managed turfgrass. At both locations, clover (*Trifolium repens*) encroachment developed by the third year of the study, but the presence of this weed had limited impact on turfgrass quality. There were few significant differences in surface hardness and shear strength between the two management practices over the entire study period. The rhizosphere microbiome data, which was collected 12, 20, and 24 months after the initiation of two programs, did not show any significant difference between the organic and conventional management athletic fields in microbial abundance and/or diversity.

The results of this study emphasize that the adoption of organic management programs on bermudagrass athletic fields should, in most instances, center on the establishment of acceptable weed tolerance levels for these fields. The use of organic management programs in the transition zone offers a viable alternative to the conventional chemical management of athletic fields, however over time, growing weed seed banks may necessitate the need for the occasional use of conventional herbicide materials.

UNDERSTANDING ORGANIC AND CONVENTIONAL MANAGEMENT PROGRAMS AND RHIZOSPHERE MICROBIOME FOR SPORTS TURF IN MARYLAND

by

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Chapter 1: Introduction

Turfgrass areas are categorized on the intended use of the site and are generally classified as home lawns, golf courses, athletic fields, and utility turfgrass areas (Babb-Hartmann, 2020). Pesticides and fertilizers are often required to maintain turfgrass quality that is commensurate with the intended use of the turf (Campbell and Wallace, 2020). There is growing concern about the use of pesticides on turfgrass and the potential exposure that may result from the use of these types of chemicals (Maxey, 2019). This has led some municipalities and larger jurisdictions to place restrictions on the use of pesticides on athletic fields. For example, the State of Connecticut prohibits the use of pesticides on school grounds including sports fields, through eighth grade (Connecticut General Assembly, 2009) while the State of New York does not allow schools or day care centers to apply pesticides to playgrounds, or athletic fields (New York Department of Environmental Conservation, 2010).

In 2015, Montgomery County, the most populous county in the State of Maryland implemented a ban on the use of EPA-registered pesticides on home lawns, public and private playgrounds, mulched recreation areas, childcare centers, and county property (Hall, 2015). Since that time elected officials in other counties within the state have proposed but not yet successfully enacted legislation similar to that passed by Montgomery County (Beyond Pesticides, 2020). The Montgomery County ban does not extend to the county's 363 athletic fields; however, pesticide use is limited to applications that aid in retaining the functional capability of the field to

support play and player safety. Montgomery Parks adheres to the principles of Integrated Pest Management in maintaining their athletic fields but is considering wholly implementing the use of organic management practices if it can be demonstrated such practices will typically result in field surface conditions comparable to those typically obtained using conventional athletic field management practices.

The occurrence of injuries on natural grass athletic fields has been linked to the surface properties of the field which are influenced both by the amount of play a field receives and the way the field is managed (Straw et al., 2020). Surface properties that can impact player safety include soil moisture, turf quality, surface shear strength and hardness (Miller and Henderson, 2013; Straw et al., 2020). Comparative studies of the aesthetic and functional properties of cool season turfgrass athletic fields managed using conventional and organic management approaches have been conducted in cool climates (Miller and Henderson 2012, 2013), however, Montgomery County is located in the northern reach of the turfgrass transition zone, an area where hybrid bermudagrass (*Cynodon dactylon L. Pers. Var. dactylon x C. transvaalensis*) is increasingly being used as the turfgrass of choice for athletic fields. Relative to cool season turfgrasses, bermudagrass generally has a higher nitrogen requirement, is less susceptible to warm season annual grass encroachment and has a contrasting susceptibility to diseases and insect pests. The different capabilities, cultural practices, and widespread use of this turf species merit examination of how

the surface properties of bermudagrass fields may be affected by adopting an "organic only" management regime in place of conventional management regime.

A central tenet of organic turf care is that improved soil health brought about by the use of natural materials, will lead to improved plant health. Soil health is the continued capacity of a soil to function as a vital living ecosystem that sustains plants, animals, and humans (Arshad and Martin, 2002; Laishram et al., 2012). Enhanced soil health includes the presence of soil conditions that promote the recycling of nutrients, which is frequently associated with presence of microorganisms that facilitate nutrient recycling (Lehmann et al., 2020). Until recently, techniques were not available to provide a comprehensive assessment of the type of microorganism that are present in the soil. With the advent of High Throughput Sequencing methods for DNA analysis, it is now possible to examine the diversity and abundance of microorganisms in the rhizosphere (Bella et al., 2013). Several studies have recently investigated turfgrass rhizosphere microbial and fungal communities. However, very little research of this type has been applied to athletic fields where the constant disruption of the surface can have a dramatic effect on soil physical properties (Chung et al., 2019) and the resulting accumulation of soil organic matter (Cookson et al., 2008).

This thesis examined three aspects of warm season turfgrass athletic field management. First, there are the comparative abilities of organic and conventional programs to sustain season-long acceptable turfgrass quality. Second, the influence of organic and conventional management programs on surface properties that can impact

player safety, and the comparative abilities of the two programs to support a diverse microbial community. Finally, this thesis also examined the ability of a widely used golf turf firmness measurement device (TruFirm) to measure the hardness of athletic fields in a manner similar to that of a Clegg impact hammer. The Clegg impact hammer is the standard device used to measure athletic field surface hardness. Gaining a better understanding of how the management practices of athletic fields affect turfgrass surface properties and microbial communities of bermudagrass will permit athletic field managers and decision makers to make better informed decisions on transitioning to organic only turf care programs in Maryland and upper regions of the transition zone.

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Chapter 2: Comparing the effect of an organic and conventional management program on sports field turf quality

Introduction

Natural grass playing surfaces are often the preferred playing surface for athletic fields. This is because the initial capital cost of these fields is less than that of artificial fields (Stiles et al., 2009, Fleming, 2011), the midday surface temperatures for natural grass field surfaces are considerably lower than those of artificial surfaces (Fleming, 2011, Liu and Jim, 2021) and because there is a growing body of evidence that indicates foot, knee, and ankle injuries occur less frequently on natural grass fields than on synthetic playing surfaces (Steffen et al., 2007; Mack et al., 2019; Paliobeis et al., 2021). As an example of the latter, Mack et al. (2019) reported there is a 16% decrease in the likelihood of the occurrence of a lower-extremity injury (i.e., knee, ankle injuries) for National Football League (NFL) athletes that play on natural grass when compared to a synthetic field playing surface. Additionally, when Paliobeis et al. (2021) examined injury incidence on artificial and natural turf, they reported out of 953 injuries, 61% occurred on artificial turf and 39% on natural turf.

Natural grass fields require water, nutrients, and pesticides to promote turfgrass growth that can recover from wear and minimize surface irregularities resulting from weed encroachment or pest damage. Irregular athletic field surface conditions arising from low turfgrass quality and high soil moisture hot spots within the field, have been reported to have a higher occurrence of ground-derived injuries on recreational sports fields (Straw et al., 2018). Pest-induced surface irregularities

can be mitigated with the use of pesticides. However, turfgrass susceptibility to wear, and its capacity to recover from it (i.e., recuperative ability), is dictated by a host of conditions, including the turfgrass species and cultivar, turf density (Canaway and Baker, 1993; Park et al., 2009; Aldahir and McElroy, 2014), turfgrass quality (Bonos et al., 2001; Murphy et al., 2013), the cultural practices to maintain the turf, and management of play on the field (Carrow,1995; Aldahir and McElroy, 2014).

Recent concerns about exposure to pesticides have resulted in a growing number of municipalities placing restrictions on the use of pesticides applied to turf. Examples of this include policies that ban the use of pesticides on municipal properties (Porter, 2013), statewide bans on the use of pesticides on school grounds, which can include school athletic fields (Campbell and Wallace, 2020; Gannett et al., 2021), and cosmetic bans on the use of pesticides within the borders of the entire municipalities (Pralle, 2006; Marshall et al., 2015). When these policies are adopted, a frequent response is to transition cultural management practices away from the use of synthetic materials to an approach that employs the use of organic fertilizers, pesticides, and other natural-based supplements.

Soil health is the continued capacity of a soil to function as a vital living ecosystem that sustains plants, animals, and humans (Arshad and Martin, 2002; Laishram et al., 2012). When added in sufficient amounts and possessing desired chemical and physical properties, organic matter can maintain or improve soil health by enhancing aggregate stability and infiltration (Murphy, 2015; Delgado and Follett, 2002), increasing the nutrient retention and pH buffering capacity of a soil (Antil and

Singh, 2007) and promoting nutrient cycling and the presence of favorable biotic agents (Delgado and Follett, 2002; Hattenschwiler et al., 2005; Six et al., 2006). Improved soil health enhances plant resilience to environmental stresses such as sub and super optimal temperatures, drought, and damage from biotic agents (Tobor-Kaplon et al., 2005; Brussaard et al., 2017).

Improvements in soil properties and plant health arising from the addition of organic matter are most easily accomplished by the incorporation of relatively large amounts of organic matter into the soil (Martinez-Garcia et al., 2018), or in the case of established turfgrass, by making frequent topdressing applications of compost. In the case of latter, compost topdressing applications, which are an integral part of many organic turf care programs, have been shown to suppress the fungal pathogens *Rhizoctonia solani*, *Sclerotium rolfsii* (Coelho et al., 2020) *Clarireedia spp.*, (Nelson, 1992; Coelho et al., 2020) *Ophiospaerella korrae* (Qian and Wilhelm, 2021), increase soil water retention, and reduce soil bulk density (Johnson et al., 2006). Improvements in turf quality have been noted with the use of compost topdressing on lawns when compared to urea-based fertilizers, however the observed differences may simply be due to a greater amount of plant available N being applied with the use of the compost topdressing material relative to the synthetic fertilizer with which it is being compared (Qian and Wilhelm, 2021; Johnson et al., 2006). In Maryland, the use of compost topdressing adheres to the same N and P loading management regulations as bagged fertilizer materials (Maryland Department of Agriculture, 2022). Because of P restrictions, this effectively rules out the use of compost topdressing as a cultural

practice on natural grass athletic fields in the state. The use of organic fertilizer materials, such as those derived from poultry products, whey, meals, oils, and digested sewage sludge have been shown to have little effect on soil organic matter and microbial biomass when compared to the use of mineral based fertilizers (Guertal and Green, 2012). This is presumably due to the relatively small amount of organic matter that is added to soil surface in comparison by frequent compost topdressing applications.

Unlike organic food production, there are no regulatory guidelines for what constitutes organic turf care. However, those seeking to codify a list of materials acceptable for use in organic turf care programs (Tukey, 2007; Workman, 2012; Babb-Hartman, 2020) have indicated that materials approved by the Organic Materials Review Institute (OMRI) are permissible for use in organic turf care. The list of materials the OMRI has approved are considered to be the most trusted and comprehensive source for materials that are permissible for use in organic turf care because the materials in the list are approved for use in the USDA's National Organic Program.

Studies comparing the quality of turf managed using mineral and synthetic based fertilizers and conventional pesticides with turf managed using organic fertilizer materials, natural supplements and OMRI approved pesticides are few in number for athletic field playing surfaces. Miller and Henderson (2012) examined the turfgrass quality of Kentucky bluegrass (*Poa pratensis,* L) subjected to wear and maintained as a simulated athletic field using either a conventional or an organic-

based suite of chemicals. The conventional program included the use of synthetic pesticides and fertilizers such as urea, siduron, quinclorac, and high salt fertilizers like potassium chloride, whereas the various organic programs were comprised of soy protein products, molasses, compost tea, *Bacillus licheniformis*, and other similar products. They reported turf maintained using conventional materials retained higher quality and had lower weed counts when compared to turf managed using organic materials. This finding is consistent with the results of a survey of turf managers in Connecticut wherein 73% of the respondents indicated they perceived a decline in school ground and athletic field turf quality when turf management switched from use of an IPM approach to a strict no pesticide use program (Bartholomew et al., 2015).

Large crabgrass *(Digitaria sanguinalis* L), smooth crabgrass (*Digitaria ischaemum* Schreb) and white cover (*Trifolium repens* L) are weeds that often appear in the absence of herbicide use when a dense stand of turfgrass cannot be maintained. In a simulated traffic study, Brosnan et al., (2014) reported a complete loss of green surface coverage occurred with 10 simulated traffic events for plots covered with large crabgrass and white clover, whereas at this same traffic intensity approximately 70% green cover remained for hybrid bermudagrass (*C. Dactylon x C transvaalensis* Burtt-Davy, 'Tifway'). Their results suggest that the substantial encroachment of these two weeds on an athletic field playing surface, followed by intensive play can compromise the safety of this surface.

While previous studies have shown cultural management practices that employ the use of conventional chemicals result in higher turf quality than

management approaches employing the use of organic materials, these studies have been limited to examining cool-season turfgrasses in the Northeastern region of the United States. Additionally, the results obtained from simulated wear athletic fields studies have not been extended to include examination of results obtained from actual athletic fields being managed using the same materials and cultivation practices. Examination of natural grass athletic fields is complicated by spatial variability in turf surface characteristics caused by non-uniform play across the field. Thus, it is important to identify and interpret the surface characteristics obtained from different regions of the field when reporting whole field averages, so that one has a more complete picture of where on the field a player might be most susceptible to injury (Straw et al., 2020).

Hybrid bermudagrass (*Cynodon dactylon L. Pers. Var. dactylon x C. transvaalensis*) is the primary warm season grass used on athletic fields in the USA (Huang et al., 2019). The excellent heat tolerance and the recuperative potential of this species makes it well suited for use in the southern half of the United States. Relative to cool season turfgrasses, bermudagrass generally has a higher nitrogen requirement, is less susceptible to warm season annual grass encroachment, and has a contrasting susceptibility to diseases and insect pests. The different capabilities, cultural practices, and widespread use of this turf species merit examination of how the surface properties of bermudagrass fields may be affected by adopting an "organic only" management regime in place of conventional management regime. Such information is needed as a growing number of municipalities in warmer regions of the

country consider the adoption of an “organic only” management regime for public sports fields. Accordingly, the objectives of this research were to:

1. Determine the effect of a conventional and organic based management program on turf quality, green cover, and weed encroachment of bermudagrass research plots maintained as an athletic field playing surface.
2. To compare the turf quality of municipal athletic fields managed using conventional and organic based materials with research plots receiving the same materials.
3. To evaluate spatial and temporal changes in turfgrass quality on municipal athletic fields managed using conventional and natural based materials.

Materials and Methods

The study was conducted from September 2019 to December 2022 and included two 59.4m by 96m multi-purpose playing fields at Laytonia Recreational Park in Gaithersburg, MD ((Latitude 39.1513^{0} N, Longitude 77.1445^{0} W) and eight, 7.6m by 9.2m field plots at the University of Maryland Paint Branch Turfgrass Research Facility (PBTRF) in College Park, MD (Latitude 39.0071^{0} N, Longitude 76.9408^{0} W). The fields at Laytonia Recreational Park (Laytonia) consisted of a 20cm depth, 83% sand, 9.0% silt, and 8% clay soil mixture cap. The surface soils of the two fields possessed a pH of 6.2, 258 to 326 mg kg^{-1} P, 69 to 78 mg kg^{-1} K and a soil organic matter content of 1.8 to 2.0%. Drainage at the site consisted of runoff from the crowned field moving into drains located approximately 3m off the sidelines of the

two fields. The field plot site at PBTRF consisted of a 15 cm, 80:10:10 sand: soil: compost mix cap overlying a native soil having a partially functioning tile drainage system. The soil cap had a pH of 6.3, 450 mg kg^{-1} P, 122 mg kg^{-1} K, and possessed 0.6% soil organic matter. Tahoma 31 bermudagrass (*Cynodon dactylon* x *Cynodon transvaalensis* 'OKC 1131') springs were broadcast at PBTRF on 22 August 2019 at an unknown rate. Immediately before sprigging, RhizoSorb® (Phospholutions, Inc., State College, PA, 16801) and Cool Terra Biochar® (Cool planet, Greenwood, Colorado, 80111) were broadcast over the site at 960 kg ha^{-1} and 785 kg ha^{-1}, respectively. The fields at Laytonia were sprigged with Tahoma 31 bermudagrass, at an unknown rate, during the last week of June in 2019, with RhizoSorb® and CoolTerra® Biochar being broadcast at this time using same rate as at PBTRF.

Chemical Treatments

The conventional and organic treatments programs were created in consultation with Montgomery County Park athletic field managers and two private turfgrass consultants. One of the consultants specializes in providing conventional management of athletic fields recommendations while the other specializes in providing organic lawn care and athletic field management consultations. The two management programs were developed to ensure that both received no P, 196 kg N ha^{-1} ^{1} yr^{-1}, 151 (organic) to 155 (conventional) kg K ha^{-1} yr^{-1} and that there was minimal variance in the cultivation practices employed between the two programs. The programs provided specific intended dates of application for each material and cultivation practice. However, because the treatments were applied over 3 successive years at two

different locations, the application dates for the various materials and cultivation practices are referenced in a general sense here with specific application dates for each year and material provided in Appendix 1.

The use of fertilizers in the conventional program consisted of the application of 39 kg N ha^{-1} of Country Club 24-0-12, 60% Mesa 100% EXPO SGN 150 (LebanonTurf, 1600 E Cumberland St., Lebanon PA 17042) in early May, 68 kg N ha^{-1} of 21-0-0 in early June and July, and 88 kg N ha^{-1} 22-0-22 containing 65% Methylene urea (The Andersons Lawn Fertilizer Division, Inc. P.O. Box 119 Maumee, OH 43537) in August and mid-September. Potassium sulfate was applied at a rate of 44 and 49 kg K ha^{-1} in early June and July, respectively. Nitrogen and K applications in the organic program relied on the use of feather meal, meat meal and blood meal derived products that contained potassium sulfate, kelp extract and potassium hydroxide. Nature Safe 10-0-8 (Darling Ingredients Inc. 5601 N. MacArthur Blvd., Irving, TX 75038) was applied at 39 kg N ha^{-1} in early April, and at 24 kg N ha^{-1} applied in early July and mid-September. In June and mid-August 24 kg N ha^{-1} was applied using a Nature Safe 9-0-9 which is devoid of kelp extract and potassium hydroxide. All fertilizer materials, as well as the corn gluten meal applications described below, were applied using a drop spreader at PBTRF. Supplemental plant and soil health products were part of the organic program and included the application of Ferti-Nitro Plus Plant Nitrogen Amino Acid (Ferti-Organic, 3006 JCS Industrial Drive, Brownsville TX 78526) at 9.8 kg N ha^{-1}, Nature's Essence Kelp (Organic Approach, 128 Weaver Road, Lancaster, PA 17603)

at 19.1 L product ha^{-1} and Nature's Wisdom Horticultural molasses (AG Organics, 450 Business Park Drive St 100, Prosper, TX 75078) at 2.4 L product ha^{-1} in early July.

Other than in fall of 2019, when a preplanned application of Velista (Penthiopyrad) was made in the conventional management program and Civitas (mineral oil) in the organic management program, disease control measures were based on field scouting which, did not support the use of fungicides for either management regime. Additionally, the two programs did not incorporate insect control measures. Weed control for the conventional program consisted of a single mid-April application of pre-emergent Oxadiazon (5-tert-butyl-3-(2,4-dichloro-5-isopropoxyphenyl)-1,3,4-oxadiazol-2(3H)-one)) (Ronstar, Bayer Environmental Science) at 3.0 kg oxadiazon ha^{-1}, and one early June application of Tribute Total; (thiocarbazone-methyl (methyl 4-({[(3-methoxy-4-methyl-5-oxo-4,5-dihydro-1h-1,2,4-triazol-1-yl)carbonyl]amino}-sulfonyl)-5-methylthiophene-3-carboxylate) + foramsulfuron (N-dimethyl-2-sulfamoylbenzamide-4-formylamino-N) + halosulfuron (methyl 3-chloro-5-[(4,6-dimethoxypyrimidin-2-yl)carbamoylsulfamoyl]-1-methylpyrazole-4-carboxylate) (Tribute Total, BASF Corporation, Research Triangle Park, NC) at rate of 11+22+34 g ha^{-1} for thiencarbazone-methyl+foramsulfuron+halosulfuron-methyl, respectively. Herbicide applications at PBTRF consisted of the use of CO_2 pressurized sprayer equipped with Tee jet 6502 (Tee jet Spraying Systems Co., Glendale Heights, IL) nozzles operated at 400 Kpa with delivery rate of 420 L ha^{-1}. The organic weed control program consisted of a

mid-April application 24 kg N ha^{-1} corn gluten meal. A second early May application 24 kg N ha^{-1} corn gluten meal was added to the organic program in 2021 and 2022. Post emergence weed control in the organic regime consisted of 38 L ha^{-1} of a 26.53% Iron HEDTA (FeHEDTA) solution **(**Fiesta, 31860 Emmenthal, Germany**)** applied in early June. At PBTRF the iron application was made in 420 L ha^{-1} water using Tee jet 6502 nozzles operating 400 Kpa. All liquid applications at Laytonia Park were applied in 467 L ha^{-1} of water using Tee Jet 11006 nozzles operating at 345 Kpa.

Maintenance Practices and Turf Traffic

Cultivation at PBTRF consisted of an early April aerification using a Redexim Verti Drain (Redexim, 427 W Outer Road Valley Park, MO 63088), having 1.9 cm diameter solid tines spaced 13 cm apart which penetrated to depth of 10 cm. Decompaction to a depth of 15 cm using IMANTS Shockwave (Imants BV, Turnhoutseweg 29, 5541 NV Resusel, NL) was imposed in late May and July, in each year of study. In 2020, 2021, and 2022 slice aerification at 10 cm apart to depth of 4 cm was performed using a Universal AERO-vator (1^{st} products Inc., 164 Oakridge Church Rd, GA 31794). Solid tine cultivation was also performed to a depth of 10 cm using 18 mm tines having 5 cm by 5 cm spacing in mid-September and mid-October of each year of the study. The same cultivation practices were employed at Laytonia with the exception that the spacing between the tines was 4 cm by 4 cm in mid-September and 7 cm by 5 cm in mid-October.

Both sites were overseeded with 390 kg ha^{-1} intermediate ryegrass (*Lolium x hybridum* Hausskn.) in early October with middle center of the Laytonia fields

receiving a second 195 kg ha^{-1} overseeding of the same ryegrass cultivar two weeks later. Turf blankets were placed over turf when the soil temperatures consistently fell below 4^0C. The blankets were removed in early March except at Laytonia in 2021 when they were removed in late March. Other than the first 2-3 weeks following the removal of the blankets the turf was mowed at 2.5 cm throughout the growing season and irrigated when signs of drought stress were apparent.

Traffic

Annual hours of play on the two fields at Laytonia were estimated from field reservation times obtained from Montgomery Parks. The organically managed field received 175, 699, and 943 hours of play in 2020, 2021, and 2022, respectively whereas the conventionally managed field received 168, 702, and 1040 hours of play in 2020, 2021, and 2022. Simulated traffic at PBTRF was imposed biweekly from 20 May to 8 August in 2021 and 20 May to 12 August in 2022 using modified Ryan GA-30 aerator. The aerification drum of the Ryan GA-30 was equipped with fabricated, spring-loaded square steel plate feet studded with 2.54 cm sharp steel spikes and had the same configuration as a Baldree traffic simulator (Kowalewski et al., 2013). The spacings between the spikes and springs were 3.81 and 10.8 cm, respectively. Traffic was imposed by making two passes over the plots with each pass perpendicular to one another.

Data Collection

Turfgrass visual quality and the Normalized Difference Vegetative Index (NDVI), were assessed monthly from April to November at both locations. Turfgrass quality was assessed visually by collectively examining the attributes of turf color, density, and uniformity using a scale 1 to 9, where 1 is the bare soil devoid of turf, 6 is mostly uniform turf surface of acceptable color, texture, density and 9 is a dense, uniform turf possessing optimal turf color. The NDVI of turf was evaluated using a handheld Field Scout CM 1000 NDVI meter (Spectrum Technologies Inc., Aurora, IL) that was directed toward turf at a 45-degree angle from an approximate height of 1 m. Turf color was evaluated only at PBTRF and was performed by collecting digital images of the turf using a Nikon (Nikon D500, Nikon Inc. 1300 Walt Whitman Road, Melville NY 11747) camera capable of capturing 21 million pixels per image. The camera lens was directed into a 60 cm X 60 cm lightbox illuminated with four 8.5W 840 Lumens 120V LED soft white EcoSmart® bulbs. Digital images were taken from a height of 58 cm at an aperture setting of f2.8. Digital images were processed using TurfAnalyzer software (Field Analyzer, Turf Analyzer; Fayetteville, AR 72701) using the standard settings for turf dark green color index (DGCI) analysis. The low and high settings for hue, saturation and brightness were 155, 15, 73 and 360, 100, 100, respectively.

The presence of smooth crabgrass, white clover, and overseeded ryegrass at PBTRF were evaluated using the line intersect method (Tennant, 1975; Soubry and Guo, 2021) when each was present, except for ryegrass in 2021 and crabgrass after 11th August in 2021. At Laytonia, crabgrass and white clover were evaluated by using

a 64-sample grid pattern over the entire field. The number of visual weed patches within a 2m radius were counted from the center of each spot of the grid. A notable presence of leaf spots typically associated with *Bipolaris* sp. was observed in June of 2021, however, it was not present to the extent that application of a fungicide was deemed necessary. Similarly, no visual damage of the turf was apparent from insects throughout the study.

Different data collection protocols were used at each location. At PBTRF, for all but the green cover and visual quality data, the plots were split into four equal quadrants with one measurement being collected from each of the quadrates. Visual quality was assessed on a plot wide basis while three equally spaced measurements of green color were collected across the width of the middle of each plot. At Laytonia, data were collected using a sports field map protocol developed by Straw and Ashwill, 2020. Sixty-four data samples were collected using an 8 x 8 sampling grid method for each field.

Soil temperature at depth 5 cm was initially collected at PBTRF site using a Toro Turf Guard sensor (Turf equipment and supply company, 8015 Dorsey Run Road, Jessup, MD 20794). However, faulty sensor readings, which were not noticed until the end of the growing season occurred in the months of October and November of 2020. In the absence of accurate soil temperature data over this time period it was decided to utilize soil temperature data from GreenCast website (www.greencast.com) after it was found the GreenCast website soil temperature data was a good predictor of soil temperature data at PBTRF based on a comparison of

data collected between 1 April and 30 September 2020 (r^2= 0.75, n= 183; data not shown).

Data Analysis

The conventional and organic treatment programs at PBTRF were arranged as a randomized complete block with each treatment being replicated four times. The programs were compared with one another using unpaired t-tests having unequal variances. The t-tests were conducted monthly over all the three years of the study or whenever data were collected when not done so monthly.

Since each treatment was applied to a single field at Laytonia no experimental error term could be generated for data collected at this site. Monthly means over the three years of the study were plotted for the two management regimes to allow for a descriptive comparison of the results obtained from PBTRF. Additionally, and in a manner similar to one aspect of two field studies conducted by Straw and Henry, (2018), temporal and spatial changes in turf quality at Laytonia were evaluated in the months of April, July, and October by reporting whole field descriptive statistics for each field and by generating a spatial grid of the sampling locations on each field using QGIS software (Straw and Henry, 2018). Grid maps for each field were generated by digitizing the park boundaries. An 8 by 8 sampling grid was created using point separation distances of 7.6 m and 13.1 m and offset distances of 3 m and 2.1 m. Data was added to the sampling grid as a layer, after which the software generated zonal statistics and the spatial maps of each field.

Results and Discussion

Paint Branch Turfgrass Research Facility (PBTRF)

Visual Quality

The soil temperatures at the PBTRF for all the three years of the study are presented in Figure 1. The monthly mean temperature over the growing season ranged from 7^0C to 28^0C with the largest year to year difference in monthly temperature observed in October. In October 2021, the mean temperature at PBTRF was 18^0C, which was 3^0C and 5^0C warmer than in October 2020 and 2022 respectively. For all other months, during the growing season the range in monthly average temperature for the three years did not exceed 3^0C.

The turfgrass quality at the PBTRF is presented in Figure 2. There was a consistent incremental increase in turfgrass quality from the months of April to June in all three years of study along with a decline in turfgrass quality from the month of September to November. A marked decline in turf quality was observed between the months September and October 2020 and October and November of 2021. In all but July 2022, turf quality evaluations at PBTRF occurred in the first two weeks of the month indicating temperature dependent quality responses were reliant to some extent on the temperatures that occurred early in the month. The dramatic decline in turf quality between October 2021 and November in 2021 is most likely the result of the warm temperatures that occurred in the first week of October of 2021 which sustained bermudagrass growth and color retention longer into the month than cooler temperatures that occurred in October 2020 and 2022. In the week prior to the collection of October 2021 data the soil temperature in College Park was 21^0C

whereas the soil temperature in 2020 and 2022 one week prior to the collection of the quality data were 15^0C and 14^0C respectively. For warm season grasses, soil temperatures below 15^0C are associated with declines in growth and chlorophyll production (Levitt, 1980, White and Schmidt, 1989) which presumably lead to the lower turfgrass quality seen in October of 2020 and 2022.

Turf maintained using the organic program possessed higher turf quality in the month of May compared to turf maintained using the conventional program in all three years of the study. The observed May response was attributed to the greater amount of early spring applied N in the organic program compared to the conventional program and removal of the ryegrass (Figure 3) resulting from mid-April application of oxadiazon in the conventional program(Johnson, 1982). In the month of April, 35% of the yearly amount of N was applied in the organic program whereas no N was applied in the conventional program. The slower rate of mineralization of N from natural organic sources requires that these materials be applied earlier in the season than inorganic forms of N to ensure most of the applied N is available for plant uptake when the growth of warm season grasses is optimal.

In July and August of 2021 and July, August and September of 2022, turf managed using the conventional program possessed higher turf quality than turf managed using the organic program. The lower turf quality seen over the summer months in turf managed using the organic program in 2022, and in the month of August in 2021, was the result of the presence of smooth crabgrass within plots receiving this treatment (Table 1). In August of 2021, 15% of plot area managed

using the organic program contained crabgrass whereas no crabgrass was present in the plots maintained using the conventional program. Previously conducted studies have demonstrated corn gluten meal provides relatively poor control of crabgrass when compared to the use of conventional pre-emergent materials (Babb-Hartman, 2020; Patton & Weisberger, 2012; John & DeMuro, 2013). Most researchers have concluded corn gluten meal possesses limited herbicide activity and that the suppression of crabgrass resulting from its use is due to the nitrogen fertilizer properties of the material (Hahn, et al., 2020). Given that the two programs were designed to supply the same amount of nitrogen, the presence of crabgrass in the organically managed plots is not surprising.

Weeds were not present in any of the management programs in 2020, presumably because no wear was imposed over the study area in 2020. Wear was not imposed in 2020 at PBTRF to match the situation at Laytonia where the fields were closed over most of the summer due to the Covid-19 pandemic. White clover ranging from 18 to 19% was present in the plots managed using the organic program in months of May and June in 2022 (Table 2). The clover presents within these plots however had a very prostrate growth habit and small leaves making it less visible from a distance than crabgrass. Because of this, the presence of white clover was deemed to be less objectionable (i.e., had less impact on turfgrass quality) than the presence of crabgrass. It appears that a single application of an iron-based post emergence herbicide is less effective at controlling clover than is use of a single application of theincarbazone-methyl+foramsulfuron+halosulfuron_methyl.

NDVI ratings

Normalized difference vegetative index (NDVI) data are presented in Figure 4 for PBTRF. With the exception of the October 2021 measurements, NDVI measures were highest in each of the three years during the months of June, August, and September, a time of the year bermudagrass growth is typically optimal in transition zone states like Maryland (Shaver et al., 2006). As was the case for turf quality, NDVI was significantly higher for the organic management program than for the conventional program in the month of May for all three years. In contrast, unlike the August 2021 and 2022 quality data, significant differences were not seen in the NDVI reading obtained at this time. This may be due to the inability of the NDVI to accurately distinguish between turfgrass weeds, which has been noted previously by Bell et al., (2009).

DGCI ratings

Digital green color index (DGCI) data are presented in Figure 5 for PBTRF. The DGCI values measure quantitative turfgrass color (greenness), which provides the estimated amount of N and chlorophyll present within the leaves of a turfgrass canopy (Caturegli et al., 2020). With a few notable exceptions, turf color responses for the two programs were similar to that observed for turf quality at PBTRF. There were fewer statistically significant DGCI differences in between the two treatments compared with turfgrass quality but the same trend of improved turf color in the month of May with the use of an organic management program was apparent. However, in contrast to visual quality ratings, there was no difference in DGCI

between the organic and conventional programs in the month of August over the entire study period. Because of the processing of the digital images with the standard setting (green turf coverage) used to evaluate color it is likely the analysis of images did not detect the presence of weeds in the organic plots (Karcher and Richardson, 2013). It is difficult to identify the difference between weeds and turfgrass through digital image analysis, which is one of the limitations of using this method for evaluating turfgrass quality (Karcher and Richardson, 2013). There was a notable decline in DGCI observed in July and August of 2020 which is in contrary to turfgrass quality ratings collected this time. The decline in DGCI in the summer of 2020 is likely related to scalping of the turf that occurred at this time. Visual quality ratings were less impacted by scalping of the turf because quality was assessed over the entire plot while the evaluation of NDVI consisted of only a portion of the plot area.

Laytonia athletic fields

Visual Quality

Visual turfgrass quality assessed monthly on the two athletic fields at Laytonia is presented in Figure 6. Except for August in 2020, turf quality was highest in the months of July and August in each year of the study. In contrast to PBTRF, there was not a consistent incremental increase in turf quality over the months in April, May, and June in 2020 and 2021. More specifically, the decline in turf quality seen in May in 2021 and 2022 was likely the result of play on the field, which did not occur in 2020 because of the Covid-19 Pandemic. In the absence of play in 2020, the

fertility and removal of ryegrass effects on the turfgrass quality seen at PBTRF were also apparent in May 2020 at Laytonia. The presence of white clover and crabgrass in the field maintained using the organic approach contributed to the lower average quality compared to the conventionally managed field in the months of July, and August in 2022 (Table 3), however the difference in quality between the two fields was relatively small.

Spatial turfgrass quality data is presented for the months of April, July, and October which corresponds with the middle months of the spring, summer, and fall seasons (Table 4, Figure 7). Spatial variability, as indicated by the standard deviation and range in values across the field, was greatest for both conventional and organically managed fields in July 2021. In July of 2020, the range and standard deviation of the turfgrass quality values in the organically managed field were the same as those observed in July 2021. However, both metrics of spatial variability were about one third the value observed July 2021 within the conventional management field. The July 2021 data revealed that wear to turf, as indicated by the turfgrass quality ratings, was most pronounced in front of goals and in and around the mid-field face off area of the fields. In July of 2020, the spatial pattern across the organically managed field was more diffuse than in July of 2021 with there being no clear pattern of declines in turf quality in the middle of the field or around both goals of the field. Given that there was no play in July of 2020 on either field, no clear reason for the pattern seen in the organically managed field was apparent. In July of 2022 declines in turf quality were limited to the face off areas of both fields. This is

because the areas around the goal mouth were resodded early in 2022 growing season.

NDVI ratings

The NDVI ratings for the two athletic fields at Laytonia Park are presented in Figure 8. Depending on the year, NDVI peaked in July or August of each year after which incremental declines were observed in 2020, 2021, and 2022. In 2021 NDVI in October was slightly greater than that measured in September. The mid-summer to November decline in NDVI was much steeper at Laytonia than at PBTRF, and again likely reflects the impact of fall play that occurred on these fields in all three years of the study. A similar decline was not seen at PBTRF because no wear was imposed in 2020, and in 2021 and 2022, wear on the plots was terminated at the end of August. The notable effect of higher NDVI seen in organically managed turfgrass in May of each year at PBTRF was not present at Laytonia in 2021 and 2022, presumably because of the play that took place on the two fields at this time. In the two years when wear was imposed at PBTRF, it was not initiated until after the May data had been collected, thus allowing the May difference in the two treatments to be more easily expressed at PBTRF than at Laytonia in all three years of the study. Slight but statistically significant improvements in NDVI seen in July of 2021 and September of 2022 at PBTRF with the use of conventional approach also appeared to be present at Laytonia with the difference between the two treatments being larger at Laytonia. Other than these two dates, monthly treatment differences in NDVI observed at Laytonia did not follow the same trend seen for dates where the two treatments were

statistically different at PBTRF. This is due to heavy play at Laytonia which led to the modest decrease in the turf density and presence of weeds at this site in 2021 and 2022.

Conclusion

Bermudagrass is increasing being selected as the turfgrass species for use on natural grass athletic fields in the northern portions of the transition zone. Public concerns about the use of pesticides in the management of athletic fields has resulted in a growing interest in the use of natural or organic based management programs. In a direct comparison of a conventional and organic management program, this study found that except for differences in weed encroachment and the removal of overseed ryegrass, the two management programs provided similar levels of turfgrass quality throughout most of the year. Corn gluten meal was largely ineffective in preventing the encroachment of crabgrass in the presence of traffic, and the use of a single spring application of an iron-based post emergence broadleaf herbicide (FeHEDTA) was only partially effective in controlling the encroachment of white clover. Over the course of the investigation, fungal pathogens and insect pests never advanced to the point of requiring the implementation of control measures for either type of pest, suggesting the need for pesticide can be quite low on bermudagrass fields. Until such a time that a natural based material can provide herbicidal activity comparable to effective synthetic pesticide options, crabgrass, and more generally annual grass encroachment, will be an issue on organically managed fields receiving significant play. The organic program implemented in this study consistently resulted in higher

spring turfgrass quality because of the earlier use of fertilizer and avoidance in the use of preemergence herbicide (oxadiazon) that removed ryegrass.

This study also examined turfgrass quality on athletic fields and in research plots for organic and conventional management treatments. The seasonal trends in the two treatments were similar for the two treatments with turf quality generally being lower in the athletic fields due to the extensive play these fields received. The intensity of the play and traffic conditions of more than 600 hours per year on each field at Laytonia affected the turfgrass quality by reducing the turf density at goal-posts and mid-field face-off areas whereas the research plots at PBTRF there was no variability in density of turfgrass across the plots.

The use of spatial maps for athletic fields for turfgrass quality is a useful tool mainly for high-performance sports like football, rugby, soccer, lacrosse, and field hockey. It helps in identifying the surface characteristics which are caused by non-uniform play across the fields. The spatial maps generated in this investigation provided a picture of what is happening in the field and where on the field a player might be most susceptible to injury, which is a crucial part for any athletic field. This can help athletic field managers optimize the turfgrass performance by improving resource use efficiency and detect and address the problems.

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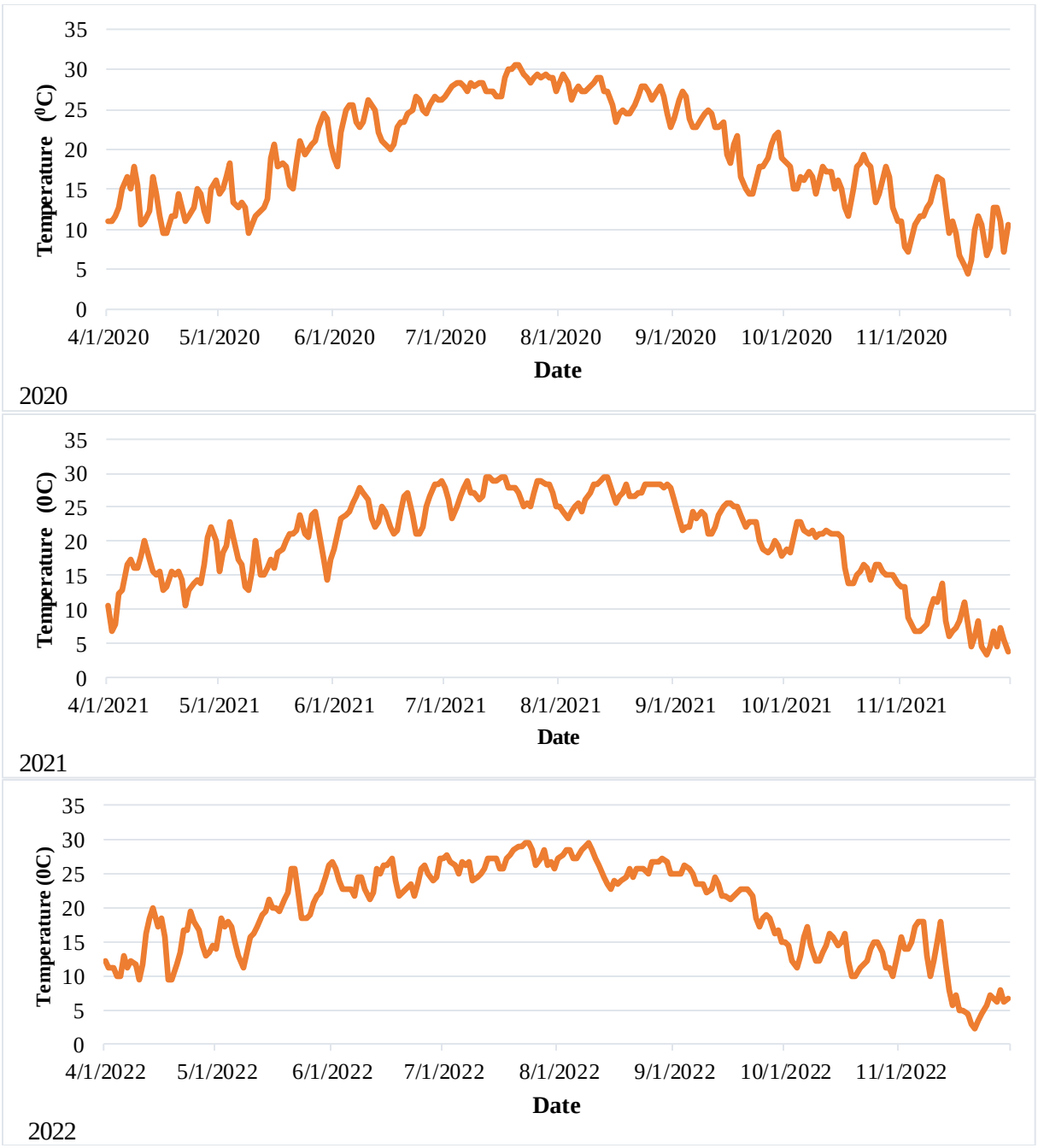

Figure 1: Soil temperatures at 3.8 cm from 1 April to 30 November in College Park MD as reported by the GreenCast soil temperature website (https://www.greencastonline.com/tools/soil-temperature) for years 2020, 2021, and 2022.

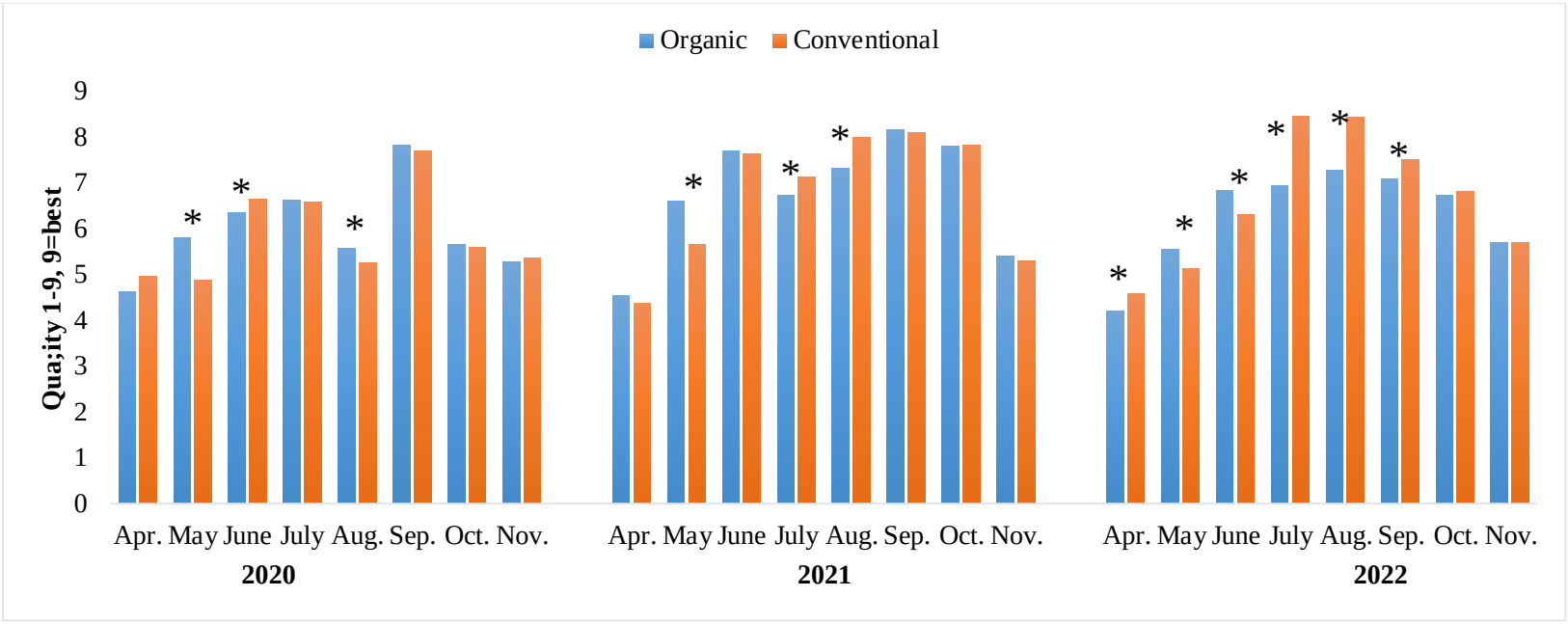

Figure 2: Turfgrass visual quality for organic and conventional management treatments at PBTRF in 2020, 2021, and 2022. Paired monthly histograms having a "*" above the pair indicate the two treatments are significantly different from one another at the P = 0.05 level.

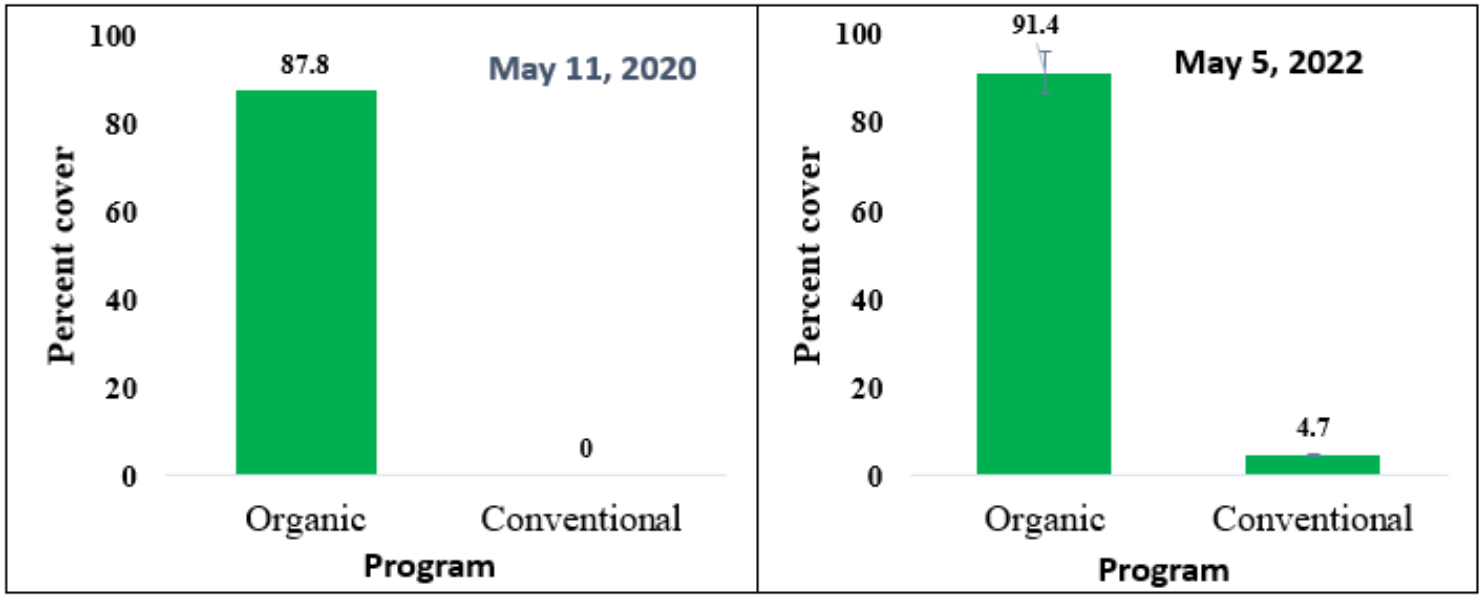

Figure 3: The percentage of ryegrass present in the PBTRF plots during the month of May for organic and conventional management program.

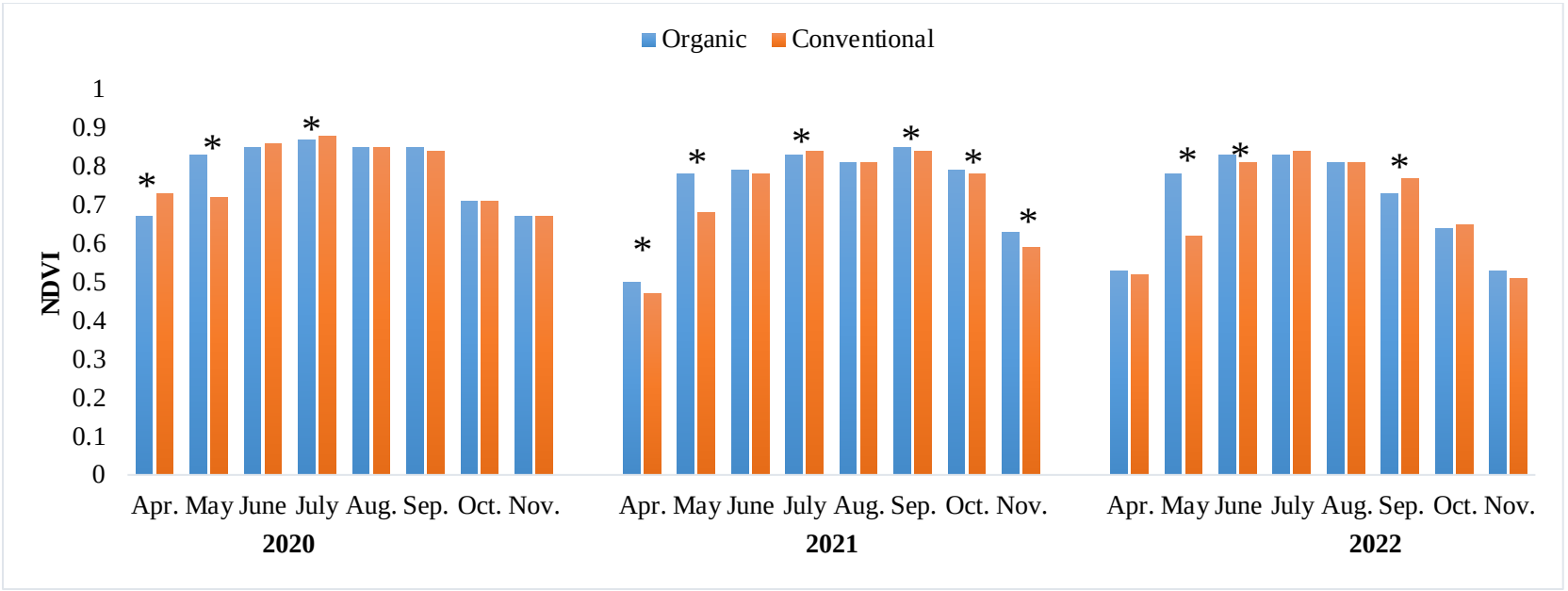

Figure 4: Normalized Difference Vegetative Index (NDVI) for organic and conventional management treatments at PBTRF in 2020, 2021, and 2022. Paired monthly histograms having a "*" above the pair indicate the two treatments are significantly different from one another at the P = 0.05 level.

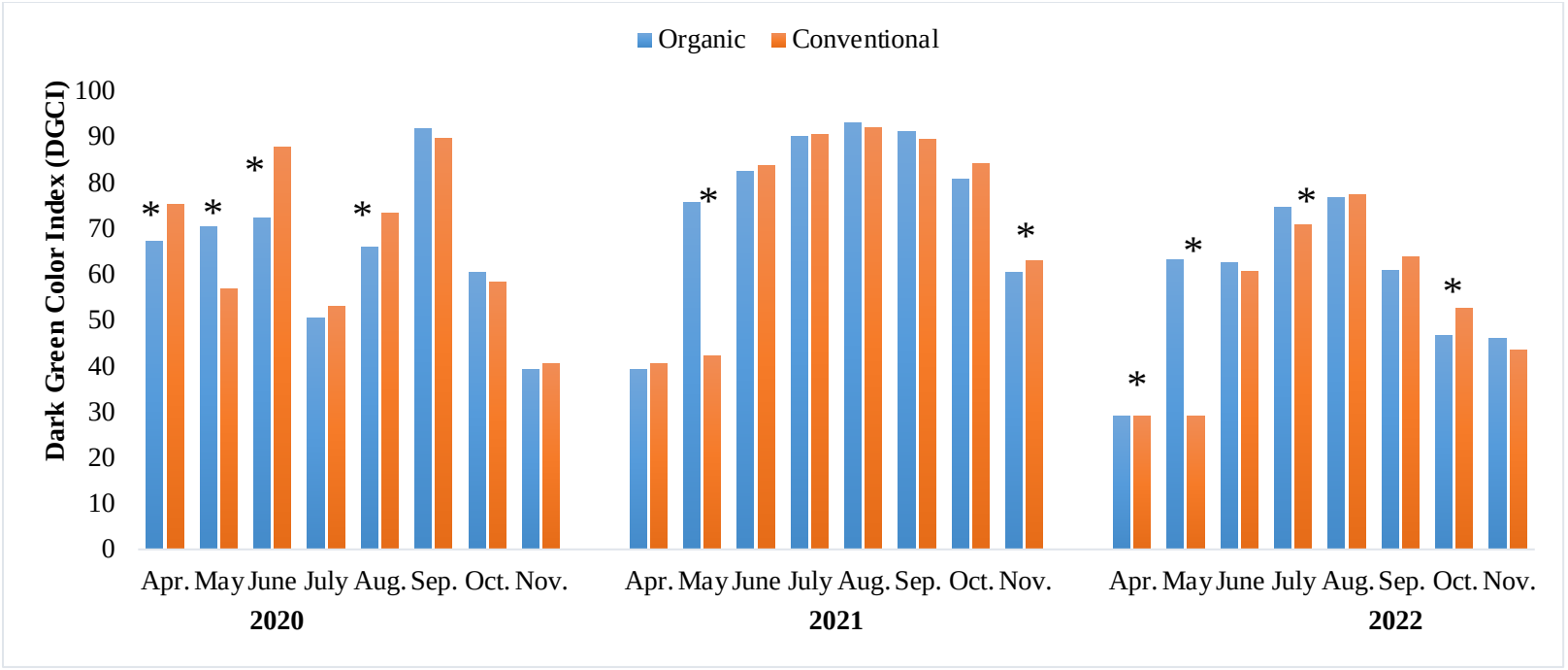

Figure 5: Dark Green Color Index (DGCI) for organic and conventional treatments at PBTRF in 2020, 2021, and 2022. Paired monthly histograms having a "*" above the pair indicate the two treatments are significantly different from one another at the P = 0.05 level.

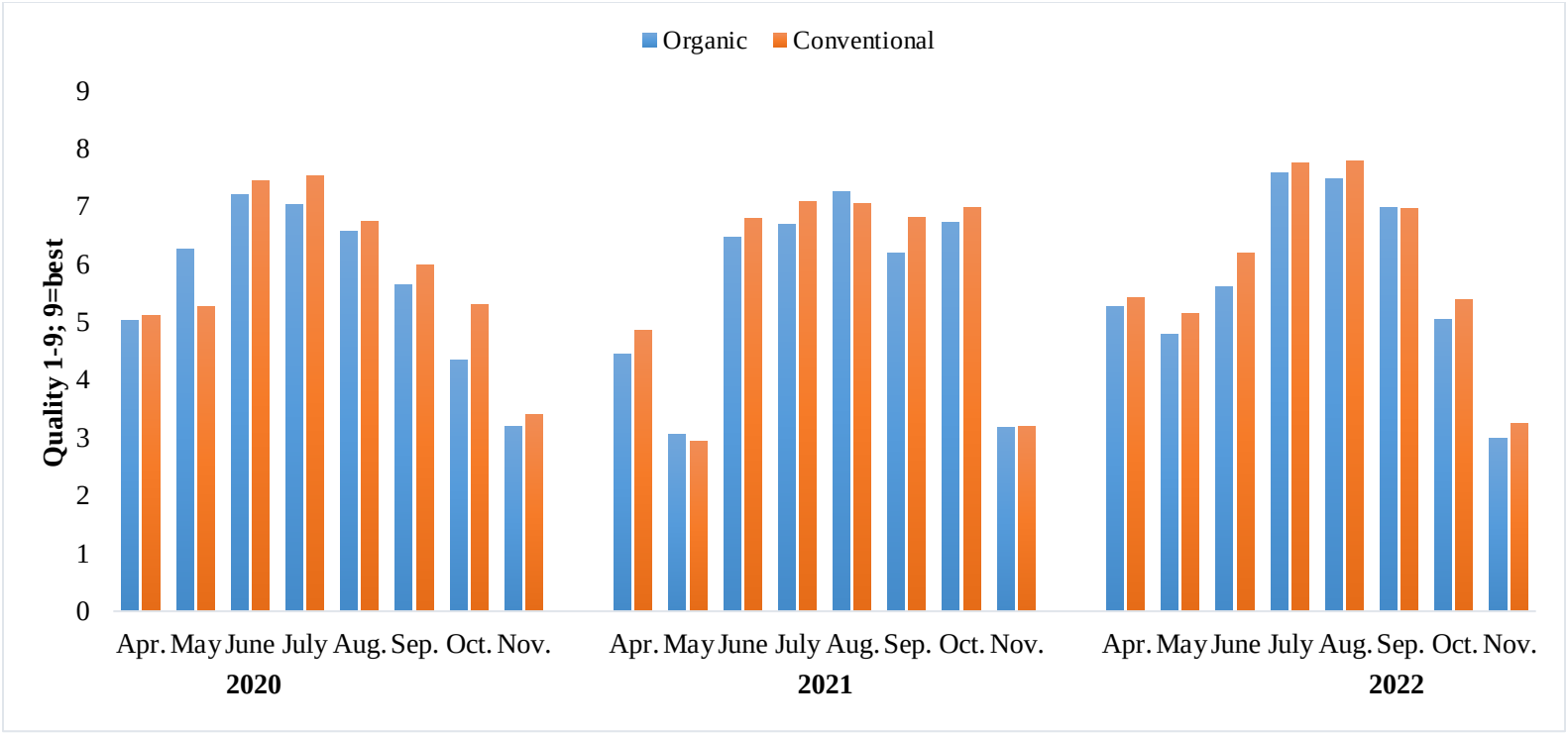

Figure 6: Turfgrass visual quality for organic and conventional treatments at Laytonia Park in 2020, 2021, and 2022.

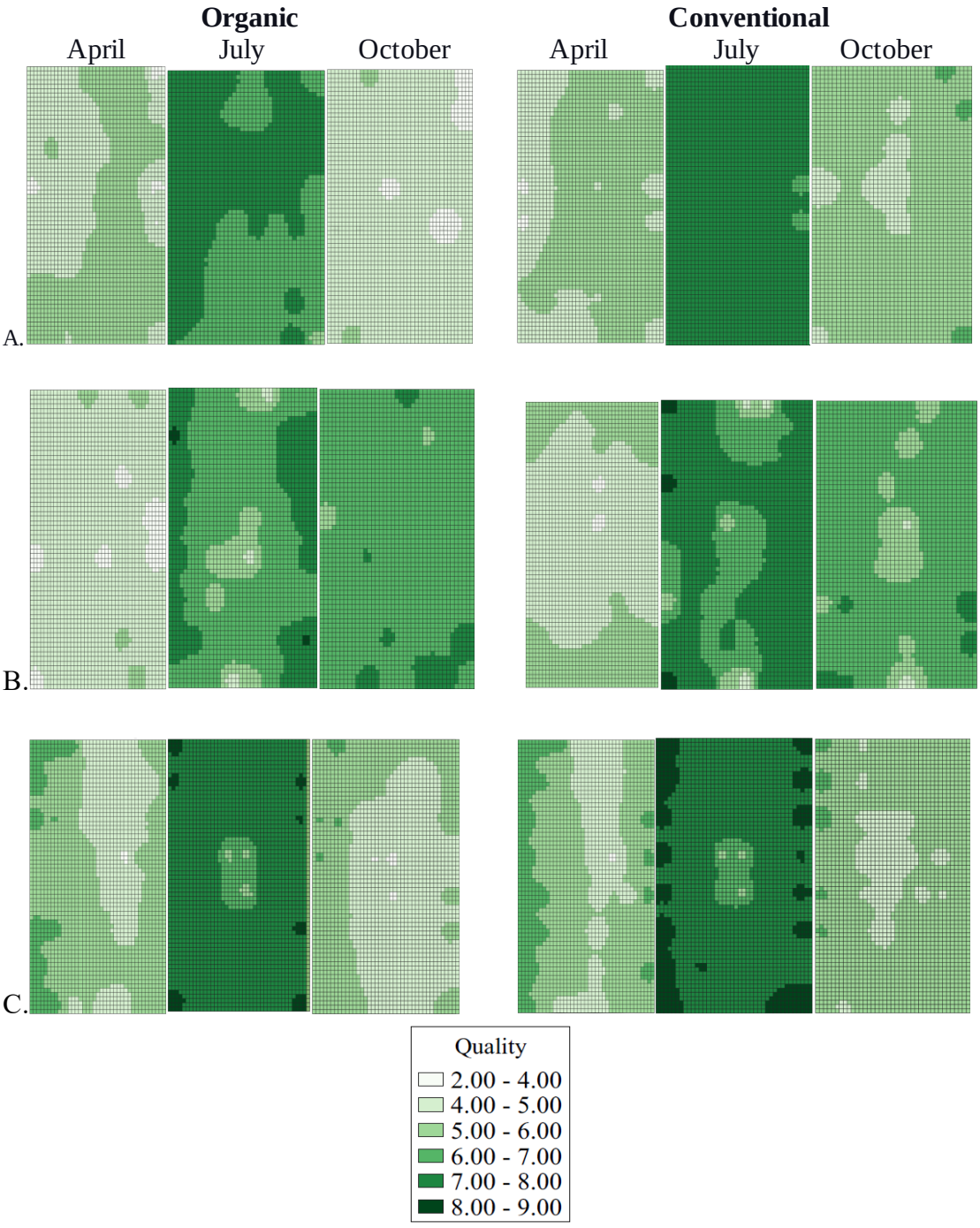

Figure 7: Spatial maps of turfgrass visual quality for the conventional and organically managed athletic fields at Laytonia Park in 2020 (A), 2021(B), and 2022(C).

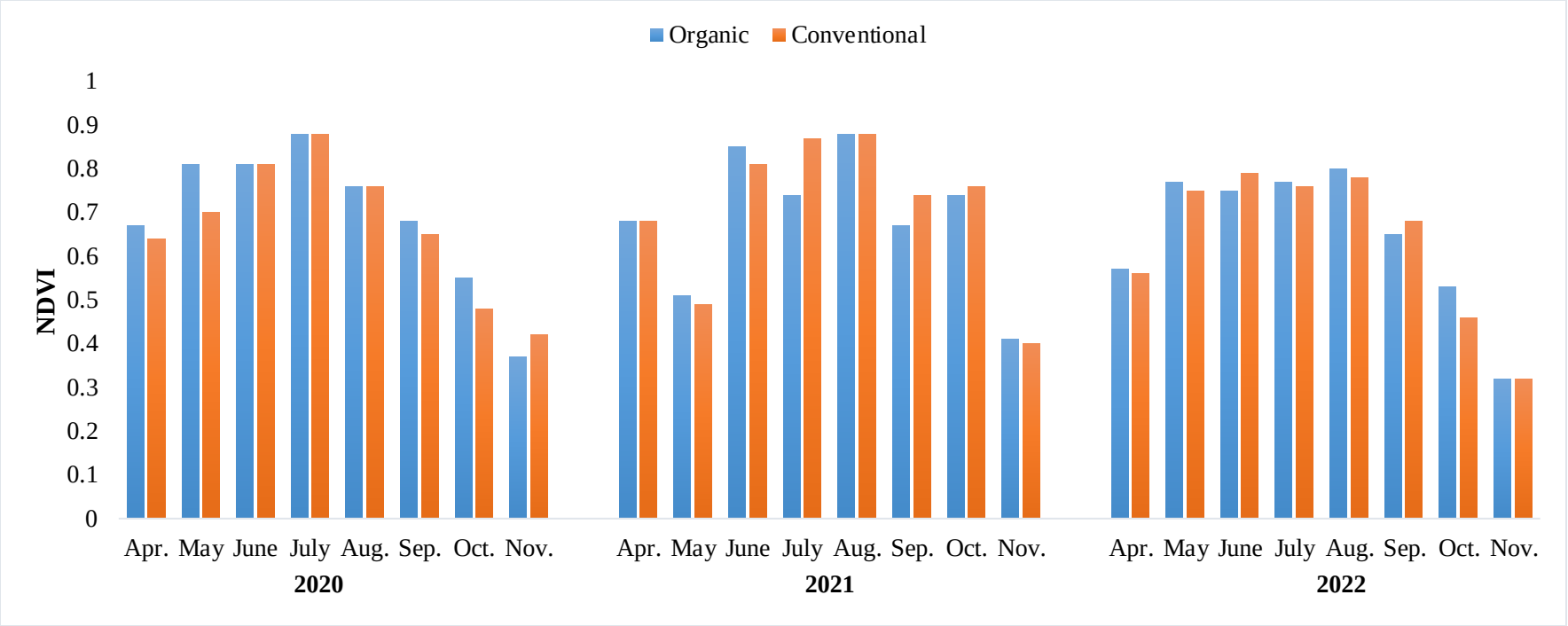

Figure 8: Normalized Difference Vegetative Index (NDVI) for organic and conventional treatments at Laytonia Park in 2020, 2021, and 2022.

Table 1: Percent crabgrass cover using the line-intersect method at PBTRF on select dates in 2021 and 2022.

Treatment	2021			2022		
	11 Aug.	**24 Aug.**		**18 July**	**11 Aug.**	**14 Sep.**
	% Cover					
Organic	14.8	15		11.9	16.4	0.6
Conventional	0	0		0	0	0
Significance	<.0001	<.0001		<.0001	<.0001	0.004

Table 2: Percent white clover cover using the line-intersect method at PBTRF on select dates in 2022.

Treatments	**5 May**	**6 June**	**18 July**	**11 Aug.**	**14 Sep.**
	% Cover				
Organic	19.1	17.9	2.6	1	6.3
Conventional	0	0.6	0	0	0
Significance	<.0001	<.0001	0.05	0.29	<.0001

Table 3: Total number of crabgrass and white clover patches observed within a 2-meter radius of 64 locations spread across the field using an 8 by 8 sampling grid unit at Laytonia Park in 2022 for the organic and conventionally managed fields.

Treatments	Number of patches				
	16 May	**17 June**	**26 July**	**24 Aug.**	**21 Sep.**
	Clover				
Organic	65	31	80	44	18
Conventional	0	0	0	0	0
	Crabgrass				
Organic	-	-	76	141	27
Conventional	-	-	0	0	0

Table 4: Turfgrass visual quality descriptive statistics for the months of April, July, and October in 2020, 2021 and 2022 for Organic and Conventionally managed athletic fields at Laytonia Park.

Year	Month	Treatment	Minimum	Maximum	Range	Mean	Standard deviation
2020	April	Organic	3.5	6.0	2.5	5.0	0.68
		Conventional	3.5	6.0	2.5	5.1	0.63
	July	Organic	4.0	8.5	4.5	6.7	1.03
		Conventional	6.5	8.0	1.5	7.6	0.36
	October	Organic	3.5	6.0	2.5	4.4	0.48
		Conventional	4.5	6.5	2.0	5.3	0.50
2021	April	Organic	3.5	5.5	2.0	4.5	0.54
		Conventional	3.5	6.0	2.5	4.9	0.61
	July	Organic	4.0	8.5	4.5	6.7	1.03
		Conventional	4.0	8.5	4.5	7.1	1.00
	October	Organic	5.0	8.0	3.0	6.4	0.54
		Conventional	4.0	8.0	4.0	6.4	0.77
2022	April	Organic	3.5	6.8	3.3	5.3	0.79
		Conventional	3.5	7.0	3.5	5.4	0.93
	July	Organic	5.0	8.2	3.2	7.6	0.63
		Conventional	5.5	8.5	3.0	7.8	0.62
	October	Organic	3.5	6.5	3.0	5.1	0.69
		Conventional	4.0	6.5	2.5	5.4	0.59

Chapter 3: Comparison of TruFirm and Clegg Impact Hammer Surface Hardness on Athletic Fields.

Introduction

The Clegg impact soil tester (CIST) is a device that measures the deceleration of a mass dropped from a standard height in units of gravity (g). It was initially developed for the highway engineering purposes; however, its use has been extended to include the measurement of the surface hardness of sports fields (Rogers and Waddington, 1990, 1992) and the firmness of golf course greens (Zontek, 2010). The CIST, when equipped with a 2.25 kg hammer is considered as the international standard for measuring the sports field surface hardness (Smeathers et al., 2010). The readings obtained using this hammer are most relevant to impact injuries such as concussion rather than fractures/non-point overuse injuries (Twomey et al., 2012). While evaluation guidelines do not exist for CIST values across multiple sports, it is generally recognized that values above 100 are associated with increased risk to player safety. The National Football League (NFL) requires that natural grass fields have surface hardness of less than 100 g prior to start of a professional football game (Serensits and McNitt, 2014). Similarly for soccer, CIST values of less than 90 and less than 100 are recommended for non-professional and professional level fields, respectively (Twomey et al., 2014). The recommended grading of CIST readings for Australian Football (i.e., Rugby) is unacceptably high (>120 g), high/normal (90-120 g), preferred range (70-89 g), low/normal (30-69 g) and unacceptably low (<30 g) (Chivers and Aldous, 2004; Twomey et al., 2012). Lower than the preferred range is

associated with the fields used by semiprofessionals and amateur footballers (Chivers and Aldous, 2004).

The United State Golf Association, in cooperation with Spectrum Technologies (Spectrum Technologies, Inc, Aurora, IL 60504), developed the TruFirm Turfgrass Firmness Meter (TruFirm). This device detects the extent of surface hardness by measuring the depth of depression caused by dropping a hemispherical object like that of a golf ball onto a surface. The TruFirm was designed to measure the firmness of golf course greens, fairways, bunkers, as well as other playing surfaces (Spectrum technologies Press Release, September 2013), with the most prevalent use being to measure the firmness of golf course greens. The TruFirm weights approximately one half the mass of a CIST equipped with 2.25 kg hammer and can be purchased for about one fifth of the cost of a CIST.

Because the CIST and TruFirm meter measure surface hardness in a different manner, there has been interest examining how readings of the two devices are influenced by soil properties as well as how well correlated the measurements are with one another (O, Brien et al., 2017; Linde et al., 2011; Stowell, 2009). Such information is useful in that it may allow the prediction of CIST values from TruFirm readings, or vice versa, if there is a strong predictive relationship between the two devices. Given the lower cost of a TruFirm it would be advantageous to have the ability to predict CIST measurements from TruFirm measurements for athletic field facilities operating on limited budgets.

Prior research comparing the two devices has focused on golf course greens with both devices showing surface hardness is influenced by soil moisture, organic matter content and bulk density (O, Brien et al., 2017; Linde et a., 2011; Stowell, 2009). The coefficient of determination (r^2) between the two devices has ranged from 0.56 to 0.75 on golf greens (Stowell et al., 2009; Woods, 2014), indicating there is a moderate correlation between the two measurements (i.e., r=0.75 and 0.87, respectively) but that confidence in predicting the measurements of one device from the readings of other is not very high considering the effect of soil properties that influence surface hardness.

In the research reported here, we were interested in expanding the examination of predicting the measurements of one device from the readings of the other by including consideration of one factor known to influence soil firmness. Further, we wished to examine the relationship between the two devices on athletic fields, where little if any published data exists. Because of the high level of play many athletic fields receive we also had an interest is seeing how the level of play a field receives would affect a comparison of the measurements obtained from the two devices.

Materials and Methods

Measurements of athletic field surface hardness were collected from two municipal park rectangular playing fields located in Gaithersburg, MD (Laytonia Park, Latitude 39.152088^0 N, Longitude 77.144487^0 W; Latitude 39.151917^0 N, Longitude 77.147004^0 W) and from an athletic field research plot area located at

University of Maryland Paint Branch Turfgrass Research Facility (PBTRF) in College Park, MD (Latitude 39.0071^0 N, Longitude 76.9408^0 W). The soil at both locations consisted of 15 to 20 cm deep 80:10:10 sand: soil: compost mix surface cap overlying the native soil at the site. The surface cap on the Laytonia park (Laytonia) fields contain 1.8 to 2% organic matter while that at PBTRF contained 0.6% organic matter. Both sites were part of an organic versus conventional management study with all areas being mowed at 2.5 cm three times per week, irrigated as needed to prevent the drought stress and receiving 195 kg N ha^{-1} yr^{-1} during the growing season. Both locations were sprigged with Tahoma 31 bermudagrass (*Cynodon dactylon x Cynodon transvaalensis* 'OKC1311') in summer of 2019 and were overseeded with 390 kg ha^{-1} of intermediate ryegrass (*Lolium x hybridum* Hausskn.) in early October of each year of the study. Additionally, half of the two fields at Laytonia received a second 145 kg ha^{-1} overseeding of the same ryegrass cultivar two weeks later.

Surface hardness readings were also collected from research putting green located at the PBTRF and from putting greens on the University of Maryland golf course (Latitude 38.592760^0 N, Longitude 76.571440^0 W). The greens at PBTRF consisted of the cultivar 007 creeping bentgrass (*Agrostis stolonifera* L.) while those at the University of Maryland golf course consisted of a mixture of Penn A1, and A4 creeping bent grass and annual bluegrass (*Poa annua* L.). The former and latter were maintained at a height of 4 mm and 3 mm respectively.

Surface hardness measurements were collected using a 2.25 kg Clegg F355 impact soil tester (Turf-Tec International, 1471 Capital Circle NW, Tallahassee, FL

32303) possessing a 5cm diameter hammer dropped from a height of 45 cm and a 6490S model Field Scout TruFirm Turf firmness meter (Spectrum Technologies, Inc., 3600 Thayer Court, Aurora, IL 60504). Hardness measurements were paired with volumetric water content (VWC) data obtained to a depth of 3 cm, using a TDR350, 6490S model (Spectrum Technologies, 3600 Thayer Court, Aurora, IL 60504). All three measurements were collected within 40 cm of each other each time hardness was assessed. The PBTRF site consisted of 8, 7.6m by 9.2m plots, where plots were split into four quadrates with four measurements being collected from each quadrant. Four plots were maintained using an organic management approach and the remaining plots were maintained using a conventional management approach involving the use of chemicals not approved for use in the USDA's certified organic farming program (Hollyer et al., 2013). At the Laytonia park location, the data was collected over the entire field using an 8m-by-8m sampling grid pattern following a protocol establish by researchers at the University of Minnesota (Straw and Ashwill, 2020). Cultivation practices were employed at both sites in a near indicial manner and included aerification in early April using a Redexim Vetridrain (Redexim, 427 W Outer Road Valley Park, MO 63088), fitted with 1.9 cm solid tines that had a forward spacing distance of 12.7 cm that penetrated to a depth of either 12.7 cm (PBTRF) or 17.8 cm (Laytonia), and decompaction to a depth of 15 cm using IMANTS Shockwave (Imants BV, Turnhoutseweg 29, 5541 NV Resusel, NL) in late May and July of each year. In 2020, 2021, and 2022, slice aerification was performed at a spacing of 10 cm to depth of 4 cm using a Universal AERO-vator (1st products Inc.,

164 Oakridge Church Rd, GA 31794). Solid tine cultivation was also performed to depth 10 cm using 18 mm tines having 5 cm by 5 cm spacing in mid-September and mid-October of each year of the study.

Measurements were collected from the Laytonia and PBTRF sites once a month from August to November in 2020; from April to November in 2021, except for the months of October and November at Laytonia, and from April to September in 2022. Monthly measurements were collected from PBTRF putting green from April 2022 to September 2022, with 40 measurements being collected each month. Data collected from University of Maryland golf course consisted of 5 measurements collected from 12 putting greens on 12 August 2022.

Traffic Simulated Wear and Data Analysis

Because of the Covid-19 epidemic, the fields at Laytonia were not open for play until August of 2020 and simulated traffic was not started until May 2021 at PBTRF. Accordingly, all PBTRF measurements collected before this time, were designated as measurements obtained from fields not receiving traffic i.e., No Traffic (NT). Measurements collected from the two fields after they were open for play were designated as being collected from fields receiving traffic i.e., Traffic (T).

Simulated wear was imposed bi-weekly on the athletic field research plots at PBTRF from 20 May to 8 August in 2021, and from 20 May to 12 August in 2022 using a modified Ryan GA-30. The Ryan GA-30 aerification unit was equipped with fabricated, spring-loaded square steel plate feet studded with 2.54 cm sharp steel spikes (Figure 9). The spacings between the spikes and springs are the same as that

present on Baldree traffic simulator (Kowalewski et al., 2013). A total of seven spikes are present on each plate. Two passes of modified Ryan GA-30 were made over the study area each time wear was imposed. Measurements collected at PBTRF prior imposition of wear in 2021 were designated as no traffic measurements (NT), while measurements collected after May 2021 were designated as being collected from field plots that had received traffic (T). When all measurements from both locations were pooled the resulting condition was labelled as NT+T.

Regression analysis (Du, 1999) of the data from the two sites was performed using SAS each site with the analysis consisting of simple linear regression where CIST surface hardness was assigned as the dependent variable. A second run of data was performed by adding VWC as the second independent variable. Data from University of Maryland Golf Course and PBTRF were pooled and subject to the same regression analysis as the combined Laytonia and PBTRF data with the exception that traffic was not considered in the analysis. Box and whiskers plots were generated for all four conditions that were evaluated and mean separation of conditions performed using the least significant difference test (PROC SGPLOT).

Results

The CIST surface hardness measurements obtained from three evaluated surface conditions are summarized in Figure 10 in the form of box and whiskers plots. This figure also provides a box and whiskers plot for when the T and NT data were pooled. Multiple pairwise comparisons of the four conditions indicated, that on average, the hardness measurements obtained from the PBTRF site prior to being

subjected to traffic (NT) had the lowest mean and median hardness and the least amount of variability of the four conditions that were evaluated. Surface hardness on the Greens was higher than it was at PBTRF before traffic was introduced. However, mean Greens CIST surface hardness was significantly lower than that obtained from PBTRF and Laytonia after traffic occurred at the two sites. Pooling the T and NT data significantly lowered the mean hardness when compared to the T condition while not increasing range of the hardness measurements beyond that observed for the T condition.

A highly significant ($P<.0001$) inverse linear relationship was observed between CIST and TruFirm measurements for the Greens, T and NT+T conditions (Table 5). In contrast, the linear relationship between the two devices was not significant for the NT condition. The standard error for the three significant linear relationships ranged from 3% (NT+T) to 6% (Greens) of the slope estimate, however the coefficient of determination values ranged from 0.35 to 0.52, indicating that there was a high degree of uncertainty in using the three equations to predict CIST g values from TruFirm readings alone.

The inclusion of VWC as independent variable in the prediction of CIST hardness from TruFirm measurements was significant for the Greens, T and NT+T conditions (Table 6). Moreover, VWC was significantly correlated with surface hardness measurement collected under non-trafficked conditions. The addition of VWC to the linear regression model raised coefficient of determination for all four conditions that were evaluated. However, with the possible exception of the

measurements collected from putting green surfaces, which had an r^2 of 0.71, confidence in using the TruFirm device to predict CIST hardness remained low even when considering VWC.

Discussion

The investigation focused on assessing the ability of the USGA's TruFirm meter to predict CIST surface hardness on a simulated athletic field surface in the presence and absence of traffic. Traffic was imposed by simulating wear on the simulated athletic field or actual play in the case of the Laytonia Park athletic fields. The predictive relationships were examined with and without consideration of VWC. Because prior research evaluated the ability of the TruFirm to predict CIST values on putting greens, this condition was also examined. The linear regression r^2 obtained on green surfaces without consideration of VWC (r^2=52) was less than reported by Stowell et al. (2009) (r^2=71) and Linde et al., (2011) (r^2=75). In the case of latter, the authors limited the collection of paired measurements to three putting greens on a single course, on a single date (n=36). Further they indicated the paired CIST and TruFirm measurements were collected within 2 cm of one another, which is considerably less than separation distance for paired measurements that took place in this investigation (i.e., up to 40 cm). It is likely that the greater number of locations (13) where samples are collected and the greater distance between the collection of the paired CIST and TruFirm measurements all contributed to the greater level uncertainty seen in the predictive relationship generated from the data that was obtained in this investigation.

Stowell et al. (2009) examined the relationship between VWC and CIST and TruFirm measurements and reported that neither the CIST nor TruFirm measurements were significantly correlated with VWC. Similarly, Linde et al., (2011) found that CIST measurements were significantly correlated with VWC on golf greens, however, confidence in the predictive relationship between the two was relatively low (r^2=44). Neither Stowell et al., (2009) nor Linde et al., (2011) examined the extent to which inclusion of VWC would reduce the unexplained variability in predicting CIST values from TruFirm measurements. The results presented in this investigation indicate accounting for the VWC on putting green surface reduce the amount of unexplained variability in predicting CST from TruFirm by about 40%. This reduction in unexplained variability allows one, with a moderate level of confidence, to predict CIST gravity values, for a 2.25 kg hammer, from TruFirm readings.

The lack of a significant linear relationship between the TruFirm and CIST measurements in the absence of traffic at PBTRF is likely due to the height at which turf was maintained. Rodgers and Waddington (1990) found that a 2.25 kg CIST hammer is less affected by the changes in mowing height than is 0.5 kg hammer. Given the lower mass and shape of plunger that is used gauge TruFirm turf surface hardness, it is likely that CIST and TruFirm have differential responses to changes in mowing height. A possible explanation is that has one increases the mowing height, the TruFirm is more responsive to changes in surface hardness than is the CIST equipped with a 2.25 kg hammer. This type of response would reduce the slope of the linear fit between the two making it less likely the slope would be statistically

different from zero. By the same reasoning the presence of numerous thin or bare areas on a field would effectively reduce the average height of the grass across the field, thus bringing the field mowing height closer to that of a putting green surface. This may explain why there were significant linear relations between the CIST and TruFirm measurements under T condition but not the NT condition.

A reduction in the portion of unexplained variation in predicting CIST values from TruFirm measurements by considering VWC for both the T and NT+T conditions is in agreement with a study reported by Chang et al., (2017). They examined the relationship between CIST and VWC on two soccer fields over a three-month period and found that the two were highly correlated, irrespective of turfgrass quality. Additional support in the form of a similar relationship between VWC and TruFirm for athletic fields (beyond the work reported here) appears to be missing from literature at this point in time. Overall, even with the inclusion of VWC data TruFirm readings are a relatively weak predictor of CIST surface hardness.

In conclusion, the research reported here increased our understanding of TruFirm and Clegg impact soil tester relationships on athletic fields. Unlike the results obtained on putting green surfaces in past studies, and, the results reported here that indicate CIST values can be predicted from a TruFirm measurements with moderate degree of confidence, the ability to predict CIST values from TruFirm measurements on higher cut athletic turf is much less certain. In the trafficked athletic field conditions examined in this study no more than 42% of variability could be accounted in a predictive linear relationship that included consideration of VWC. In

the absence of traffic there was no relationship between CIST and TruFirm's measurement for a simulated athletic field maintained at 25 mm. The result of this study highlights the need to investigate the relationship between the two devices at various mowing heights. It would also be beneficial to expand the research to include other soil and turfgrass properties to assess their importance in forming predictive relationships between CSIT and TruFirm measurements.

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Figure 9. The steel plate used in Ryan GA -30 aerification for imposing traffic to the PBTRF research plots

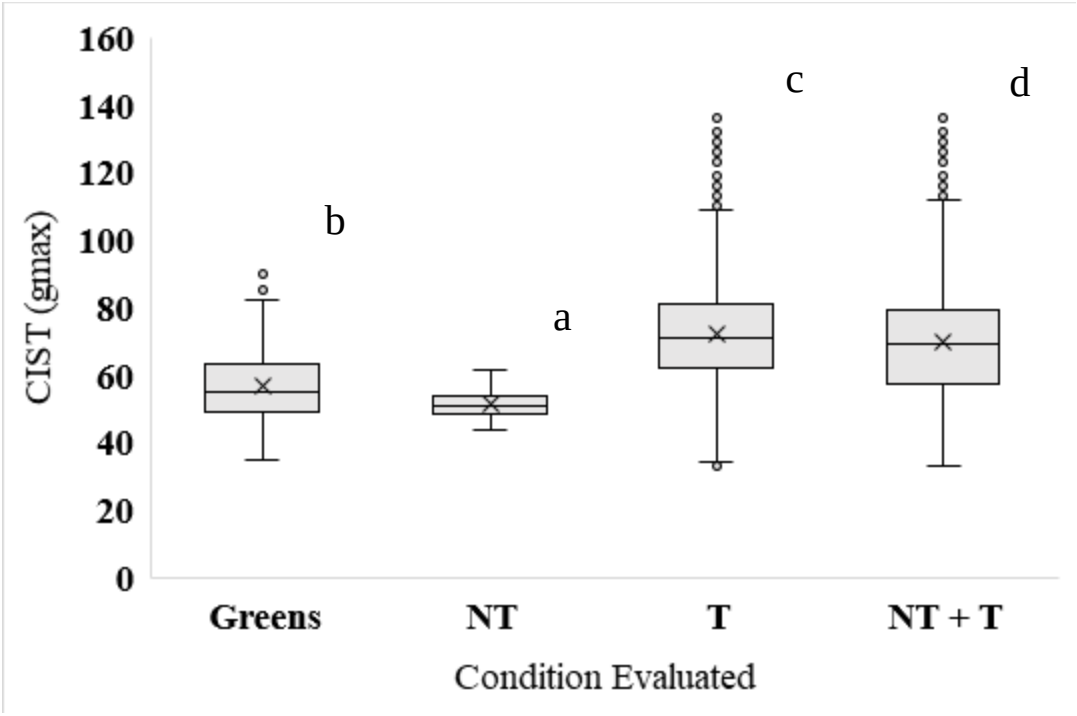

Figure 10. Box and whiskers plot for Clegg impact soil tester measurements (CIST) collected from putting greens, research plots not subjected to traffic (NT), athletic fields and research plots subjected to traffic (T), and trafficked and non-traffic measurements combined (NT + T). Conditions having different letters are indicative of mean gmax for the condition being significantly different from other conditions at the P<.05 level, using the least significant difference test.

Table 5: Simple linear regression model estimates and statistical tests for predicting CIST hardness from TruFirm measurements collected from putting greens, research plots not subjected to traffic (NT), athletic fields and research plots subjected to traffic (T), and trafficked and non-trafficked measurements combined (NT+T).

	Model Pr<F	**Slope**	**Standard Error**	**r^2**	**n**
Greens	<.0001	-36.46	2.1959	0.52	260
No Traffic (NT)	0.199	-	-	-	192
Traffic (T)	<.0001	-50.97	2.0083	0.29	1600
NT + T	<.0001	-55.47	1.7780	0.35	1792

Table 6: Multiple linear regression results when predicting CIST hardness from TruFirm and volumetric water content (VWC) measurements collected from putting greens, research plots not subjected to traffic (NT), athletic fields and research plots subjected to traffic (T), and trafficked and non-trafficked measurements combined (NT+T).

	Pr>F	Pr > |t|		r^2	n
	Model	TruFirm	VWC		
Greens	<.0001	<.0001	<.001	0.71	260
No Traffic (NT)	<.0001	<0.080	<.001	0.27	192
Traffic (T)	<.0001	<.0001	<.001	0.40	1600
NT + T	<.0001	<.0001	<.001	0.42	1792

Chapter 4: Surface Hardness and Shear Strength of Athletic Fields Maintained Using Organic and Conventional Management Practices

Introduction

Athletic field surface stability is the susceptibility of the playing surface to damage from surface forces caused by player movements (Anderson et al., 2018). Inadequate surface stability can cause players to stumble and fall and may result in jarring of limbs, muscle soreness, and a greater risk of injury in the event of a fall (Aldous, 1999). On natural grass fields, the presence of many divots is a good indicator of poor surface stability (Anderson et al., 2018). Surface stability on natural grass fields depends on turf age, surface hardness, water content, and root zone density (Bigelow and Soldat, 2013; Dickson et al., 2018). Adams et al., (1985) have reported that turfgrass roots can increase the shear strength of sandy soils and Tengbeh (1993) reported that a well-developed grass root system could increase the surface stability of fine texture soils from 500 to 850% compared to the same soil devoid of turf and roots.

The surface stability of natural grass fields is most widely characterized by measuring the shear stability of the root system. Resistance to tearing the turf caused by a rotational force imposed on the upper portion of the root system can be measured using a shear vane or shear strength tester (Mascitti et al., 2017). This type of device measures the peak rotational resistance, which is analogous to the rotational force an athlete imparts when pivoting a foot on the turf's surface. While several types of

shear vane apparatus have been developed over the years, a handheld version of a shear strength tester developed by Turf-Tec International (1471 Capital Circle NW, Tallahassee, Fl-32303) has been widely used to assess the peak rotational resistance on natural grass sports turf surfaces. The units of measure for shear strength are Newton-meters (Nm). Shear strength values for the athletic fields typically span four categories, low (<10 Nm), where the turf can easily tear apart, fair (10-15 Nm), good (15-20 Nm), exceptional (>20 Nm) (Dyer, 2017).

Surface hardness is the ability of a surface to absorb the impact of energy created by an object striking that surface (Rogers III, 1988). Player safety is correlated with surface hardness. When running on hard surfaces, players experience greater impact forces on the foot (Low and Dixon, 2014) than any other body part. Chivers et al., 2005, reported that increasing surface hardness of grass fields leads to a higher incidence of anterior cruciate ligament (ACL) injury. Similarly, head injuries are more likely to occur on hard playing surfaces (Shields and Smith, 2009). Approximately 15% of concussions that occur in high school sports such as soccer and football are from head injuries related to playing surfaces (Meehan et al., 2010). The playability and occurrence of injury on athletic fields is influenced by the uniformity of a field. In fields having excessive soil moisture and erratic surface properties the incidence of injury is higher than fields having uniform surface properties (Straw et al., 2020).

The Clegg Impact Surface Tester (CIST) has become the standard to assess surface hardness and is relied upon by the National Football League (NFL) to

measure surface hardness of fields prior to games. The NFL requires that a field have surface hardness deceleration hardness values less than 100 g within 72 hours prior to the start of a game (Serensits and McNitt, 2014; Viano et al., 2009).The recommended CIST readings for Australian Football are unacceptably high (>120 g), high (90-120 g), preferred range (70-89 g), low (30-69 g) and unacceptably low (<30 g) with the units of measure surface hardness being gravity or g-max (Twomey et al., 2012).

Surface properties of athletic fields have within-field variations due to differential foot traffic. Spatial maps of athletic fields surface properties can aid in identifying where certain type of injuries may be more prevalent , or where athletes may change the way they play in response to changing field surface properties (Straw et al., 2018). Straw et al., (2019) have generated clegg hammer and shear strength spatial maps for bermudagrass athletic fields. However, with this exception irrigation management, such maps have not been generated to evaluate the effect of various management practices these two field surface properties. Knowledge of spatial changes in field surface properties can aid athletic managers in identifying problem areas on the field, where they can then target corrective measures to address the identified problem areas.

Soil moisture content can influence shear strength and surface hardness. Although findings concerning the later have not always been consistent. Clarke and Carre (2017) studied gravimetric moisture content, studded shoe-surface interactions, on soccer fields and found that low moisture content will reduce shear strength due to

low stud penetration. They also found that high soil moisture reduces shear strength due to lubricating effect of the moisture. The results of Clarke and Carre (2017) indicate the relationship between shear strength and soil moisture is not a linear one. Straw et al., (2017) evaluated the effect of volumetric water content on surface hardness of recreational sports fields and concluded that the surface hardness was not influenced substantially by soil moisture. In contrast Li et al., (2009) have reported that soil moisture content is positively correlated with the peak deceleration (i.e., g-max), leading the authors to state that both soil water content and peak deceleration should be measured when assessing surface hardness.

Due to concerns with exposure to pesticides, some municipalities and at least two states have implemented partial bans on the use of pesticides on athletic fields. Examples include the State of Connecticut which prohibits the use of pesticides on school grounds through eighth grade and the State of New York in which no school or day care center can apply pesticides to any playgrounds, turf, or athletic fields (Connecticut General Assembly, 2009; New York Department of Environmental Conservation, 2010). When policies such as these are adopted, a frequent response is to transition cultural management practices away from the use of synthetic materials to an approach that employs the use of organic fertilizers, pesticides, and other natural-based supplements. A study conducted by Miller and Henderson (2013) examined the effect of organic and conventional management regimes on surface hardness and rotational traction of simulated Kentucky bluegrass (*Poa pratensis* L.)

athletic fields. They reported that the management regime did not affect either surface condition nor the amount of organic matter in the soil.

Hybrid bermudagrass (*Cynodon dactylon L. Pers. Var. dactylon x C. transvaalensis*), is often preferred for use on athletic fields over cool season turfgrass species in the northern half of transition zone because of bermudagrass's superior heat tolerance and lower water use requirements (Dickson, 2017; Burgin, 2021). Guertal and Green, (2012) examined the effect of organic fertilizers on bermudagrass growth but not in the context of athletic fields. Their results indicate that the organic matter content of soil will not be significantly altered by the use of organic fertilizer materials when compared to the use of synthetic or conventional fertilizer matters. This suggests that soil surface hardness will not be altered with the use of organic fertilizers in place of synthetic or conventional fertilizer materials.

The objective of this project was to determine the effect of a conventional and organic based turf management program on the surface hardness and rotational shear strength of bermudagrass athletic fields while accounting for soil moisture variability; and understanding the spatial changes in surface hardness. The approach taken to was to collect replicated treatment data from a simulated athletic field site and then to compare these results with those obtained from two athletic fields, where one field was managed using conventional fertilizer and pesticide materials, and the other managed using fertilizer and pesticide practices consistent with organic turf care.

Materials and Methods

Surface hardness and shear strength readings were collected from athletic field research plots at the University of Maryland Paint Branch Turfgrass Research Facility (PBTRF) in College Park, MD (Latitude 39.00710 N, Longitude 76.94080 W) and on two rectangular playing fields located at Laytonia Recreational Park (Laytonia) in Gaithersburg, MD (Latitude 39.1520880 N, Longitude 77.1444870 W; Latitude 39.1519170 N, Longitude 77.1470040 W). The fields at Laytonia consisted of a 20 cm depth, 83% sand, 9% silt, and 8% clay soil mixture cap with soil organic matter content of 1.8 to 2.0% while the research site at PBTRF consisted of a 15 cm, 80:10:10 sand: soil:compost mix with 0.6% soil organic matter overlying a native soil. Both locations were sprigged with Tahoma 31 bermudagrass (*Cynodon dactylon* x *Cynodon transvaalensis* ' OKC1311') in the summer of 2019.

Management programs

The two treatment programs consisted of the turf receiving 195 kg N ha^{-1} yr^{-1}, no P, and 151 kg K ha^{-1} yr^{-1} (organic) to 155 K ha^{-1} yr^{-1} (conventional) during the growing season for three successive years. Overseeding consisted of 390 kg ha^{-1} of intermediate ryegrass (*Lolium x hybridum* Hausskn.) in early October of each year of the study. Additionally, half of the two fields at Laytonia received a second 145 kg ha^{-1} overseeding of the same ryegrass cultivar two weeks later. The treatments for both locations were initiated in late fall of 2019 and are specified in detail in Appendix 1 of this thesis. In brief, the conventional program fertilizer applications included Country club 24-0-12 60% Mesa 100% EXPO SGN 150 (LebanonTurf,

1600 E Cumberland St., Lebanon PA 17042), potassium sulfate, and material containing 65% of N as methylene urea (The Andersons Lawn Fertilizer Division, Inc. P.O. Box 119 Maumee, OH 43537) whereas the organic fertilizers included Nature Safe 10-0-8 (Darling Ingredients Inc. 5601 N. MacArthur Blvd., Irving, TX 75038), Nature safe 9-0-9, and corn gluten meal. Soil enhancers and soil health products were additionally part of the organic program and included a single yearly application of Ferti-Nitro Plus Plant Nitrogen Amino Acid (Ferti-Organic, 3006 JCS Industrial Drive, Brownsville TX 78526), Nature Essence Kelp (Organic Approach, 128 Weaver Road, Lancaster, PA 17603), and Nature's Wisdom Horticultural molasses (AG Organics, 450 Business Park Drive Ste 100, Prosper, TX 75078). Fungicides were not used in this study whereas preemergence weed control consisted of the use of Oxadiazon (5-tert-butyl-3-(2,4-dichloro-5-isopropoxyphenyl)-1,3,4-oxadiazol-2(3H)-one)) (Ronstar, Bayer Environmental Science) and corn gluten meal within the conventional and organically managed areas, respectively. Post emergence weed control was limited to a single annual application of thiencarbazone-methyl+foramsulfuron+halosulfuron-methyl, (thiocarbazone-methyl (methyl 4-({[(3-methoxy-4-methyl-5-oxo-4,5-dihydro-1h-1,2,4-triazol-1-yl)carbonyl]amino}-sulfonyl)-5-methylthiophene-3-carboxylate) + foramsulfuron (N-dimethyl-2-sulfamoylbenzamide-4-formylamino-N) + halosulfuron (methyl 3-chloro-5-[(4,6-dimethoxypyrimidin-2-yl)carbamoylsulfamoyl]-1-methylpyrazole-4-carboxylate) (Tribute Total, BASF Corporation, Research Triangle Park, NC) in the conventional

management program and 26.53% Iron HEDTA (FeHEDTA) solution **(**Fiesta, 31860 Emmenthal, Germany**)** in the organic management program.

Both sites and management programs received near identical cultivation practices throughout the growing season and are described in detail in Appendix 1. In brief, cultivation practices consisted of aerification using a Redexim Verti Drain (Redexim, 427 W Outer Road Valley Park, MO 63088), having 1.9 cm diameter solid tines spaced 13 cm apart which penetrated to depth of 10 cm. Decompaction to a depth of 15 cm was performed using IMANTS Shockwave (Imants BV, Turnhoutseweg 29, 5541 NV Resusel, NL) while slice aerification at 10 cm apart to depth of 4 cm was performed using a Universal AERO-vator (1st products Inc., 164 Oakridge Church Rd, GA 31794) solid tine aerification to a depth of 10 cm was performed using 18 mm tines having 5 cm by 5 cm of spacing. At Laytonia, cultivation practices similar to PBTRF were employed with the exception of solid tine aerification which was done using a tine spacing of 4 cm by 4 cm in mid-September and 7 cm by 5 cm in mid-October.

Turf maintenance and play

All the areas were mowed at 2.5 cm three times per week, during the growing season, and irrigated as needed to prevent drought stress. Natural play occurred in Laytonia starting from August 2020. At Laytonia in 2020, the organic and conventional plots received 175 and 168 hours of play respectively. In 2021 the organic and conventional fields received 699 and 702 hours respectively while in 2022 these same two fields received 943 and 1040 hours of play respectively. The

playing season at Laytonia began in April and continued on until the end of November in 2021 and 2022.

At PBTRF, simulated traffic was started in May 2021 and was imposed bi-weekly on the research plots in PBTRF from 20 May to 8 August in 2021, and from 20 May to 12 August in 2022 using a modified Ryan GA-30 (Textron Golf, Turf & Specialty Products, PO Box 7708, Charlotte, NC 28241-7708). The Ryan GA-30 aerification was equipped with fabricated, spring-loaded square steel plate studded with 2.54 cm sharp steel spikes. The spacings between the spikes and springs were the same as that present on Baldree traffic simulator (Kowalewski et al., 2013).

Data Collection

The PBTRF plots were 7.6 m by 9.2 m plots and were split into four quadrants with four measurements collected from each quadrant. At Laytonia, the data was collected over the entire field using an 8 by 8 sampling grid pattern following a protocol established at the University of Minnesota (Straw and Ashwill, 2020).

Except for the month of November 2021 at Laytonia data was collected monthly during the growing season beginning in August of 2020 and continued through November of 2022. Surface hardness was measured using a 2.25 kg Clegg F355 impact soil tester (Turf-Tec International, 1471 Capital Circle NW, Tallahassee, FL 32303) possessing a 5cm diameter hammer dropped from a height of 45 cm. Shear strength was measured using a Turf-Tec Shear Strength Tester (Shear Vane) TSHEAR2-M (Turf-Tec International, 1471 Capital Circle NW, Tallahassee, FL 32303). The shear vane was inserted into the soil and twisted with the torque handle

until the turf started to tear. The gauge on the device equipped with a needle marker that provides the rotational force (Newton-Meters (N-m)) at the point when tearing of the turf begins to occur. Soil volumetric water content (VWC) was collected using TDR350, 6490S model (Spectrum Technologies, 3600 Thayer Court, Aurora, IL 60504) to a depth of 3 cm. All the three measurements were collected with 40 cm of one another.

Data Analysis

The experimental design at PBTRF was a randomized complete block with the conventional and organic treatment regimens being replicated four times. Analysis of variance was performed using the general linear model (Proc GLM) available in the 9.4 version of SAS (SAS Institute, 2013), with the year of study being treated as a random variable. The treatment by month by year interaction was found to be significant ($P < .0001$) for surface hardness and shear strength data, so the treatment means for this interaction were subject to unpaired t-tests having unequal variances. Because each treatment was applied to a single field at Laytonia no experimental error term could be generated for data collected at this site.

Regression analysis of the pooled data from the two sites was performed using Excel and consisting of evaluating of linear relationship between surface hardness (CIST) and volumetric water content (VWC) and shear strength and VWC, where CIST and shear strength variables were normalized to the highest soil moisture content reading obtained in the investigation.

Results and Discussion

The CIST surface hardness measurements for PBTRF and Laytonia are presented in Figure 11 for 2020, 2021, and 2022. The higher the deceleration value, the greater is the surface hardness. Over the entire study period, there were no consistent effects observed between the organic and conventional treatments for the surface hardness values at either site indicating management treatment had little effect on surface hardness. Similar findings were reported by Miller and Henderson (2013), who examined the effect of different management practices on the surface hardness on simulated athletic fields and concluded that there was essentially no difference in the surface hardness of the fields managed using organic and conventional management approaches. Similarly, in a study of athletic fields managed involving the use of organic, pesticide-free, and conventional management practices Maxey (2019) reported that there was no difference in surface hardness among the three treatments. Laytonia surface hardness was higher than the PBTRF for all the three years of study period regardless of management practice. This is the result of the extensive play that occurred on fields at Laytonia throughout the time measurements were collected. At PBTRF, simulated traffic was applied every other week for only three months per year, and only in 2021 and 2022, which was a less intensive simulation of traffic than what took place in Laytonia. Brosnan et al., (2015) reported that surface hardness readings are significantly correlated with simulated traffic conditions and noted that surface hardness increased from 48g to 68g as the number of frequencies of applied traffic increased from 0 to 18 events.

Spatial surface hardness data for the two Laytonia fields is presented for the months of April, July, and October in Table 7, and Figure 12. Spatial variability, as indicated by the standard deviation and range in values across the field, was greatest for July 2022 for both organic and conventional fields. In July of 2021, the range and standard deviation of surface hardness values were almost half of the values observed in July 2022 for both organic and conventionally managed fields (Table 7). The greater variability seen in July 2022 was likely due to the high rate of play that occurred on the field at that time. While monthly data for the amount of field play was not available to review, given that secondary schools enrollment is much lower in the summer months it is likely that more play was received on the two fields over the summer months than in spring and fall. Surface hardness readings were unacceptably high (>100 g) on athletic fields irrespective of the management practices during summer of 2022 near the center of the field and goal mouths. This is because most of the player surface interaction happens in these areas and made the soil compact and hard. The range in surface hardness values always encompassed at least two of the surface hardness categories summarized by Twomey et al., (2012) and in the month of July 2022, included values that would preempt use of the field for a professional football game in the United States.

The shear strength for PBTRF and Laytonia sites are presented in Figure 13 for 2020, 2021, and 2022. The higher the value, the greater the resistance of the turfgrass to tear apart and form divots. There was no consistent effect between organic and conventional management practices for shear strength in 2021 and 2022,

suggesting that the management practices did not have an effect on the shear strength of established turfgrass. The results are consistent with the results reported by Miller and Henderson, (2013). In 2020 at PBTRF, the conventionally managed turf showed significantly higher shear strength values than the organically managed turf during all months except for the month of October. A similar trend was not observed at Laytonia in 2020 (Figure 13). The difference in results obtained from two sites may be because the fields at Laytonia were sprigged earlier in the summer of 2020 (late June) than in PBTRF (22 August), which presumably resulted in a more extensively developed root system at Laytonia than within the plots at PBTRF. The timing and use of quick release fertilizer in the summer of 2020 may have resulted in the conventional management treatment facilitating rooting of the bermudagrass (Sartain, 2002). Both PBTRF and Laytonia yielded fair to good (10-20 Nm) shear strength values for all the months of the study period regardless of management practices used to maintain the athletic fields.

The soil moisture (volumetric water content) relationship with surface hardness and rotational shear strength are presented in Figure 14. The scatter plots showed a weak, linear relationship between soil moisture and surface hardness; however, this relations were statistically significant ($Pr > t = <0.0001$). A very weak, linear relationship also existed between shear strength and soil moisture; however, the relationship between these two was also statistically significant ($Pr > t = <0.0001$). The results indicated that while both shear strength and surface hardness affected by soil moisture content, little variability in a linear relationship of the two can be

explained by soil moisture alone. In contrast to the positive relationship seen between soil moisture ad shear strength in this study, Tengbeh, (1993) reported the shear strength decrease with soil moisture. The soil moisture surface hardness relations seen in this current study agreed with a study conducted on athletic fields by Clarke and Carre, (2017) who reported that surface hardness decreased with increasing soil moisture. In this current study, weak correlation were observed between soil moisture and surface hardness ($r = 0.28$) and shear strength ($r = 0.08$). The weak correlations may be due to the enormous number of data ($N = 2944$)that were collected, which spanned three years and two site locations.

Conclusion

Athletic field surface properties such as hardness and shear strength can be highly variable, with the amount of play being a primary determinate of the extend of variability. Given the importance of shear strength and surface hardness on player safety and performance there is a clear need to understand how recent trend to "organic only" management of athletic fields. In this study of a comparison of organic and conventional management practices on athletic fields, it was found that surface hardness and rotational turfgrass shear strength were not significantly affected by the organic and conventional management programs. However, the surface hardness values were affected by the traffic conditions making the surface harder at Laytonia Park where annual traffic of more than 700 hours occurred. With the increase in surface hardness and athlete-surface interactions there is an increased possibility of injury occurrence.

The spatial maps created for the surface hardness were useful in understanding within-field variability and the areas that were most used in the athletic fields. Areas near goal mouth and mid-field faceoff areas showed higher values of surface hardness indicating these areas were potential hotspots for increased incidence of injury. The spatial mapping technique was effective in identifying the areas of field that had excessively hard surfaces. The occurrence of hard surfaces can be alleviated by the increased use of cultivation practices, such as aeration, that will reduce soil compaction.

Soil moisture (volumetric water content), surface hardness and turfgrass shear strength are the field properties which are related to each other and considered important characteristics for the sports turf athletic fields. In this study it was found that weak correlations exist between soil moisture and surface hardness, soil moisture and shear strength and there was a negative relationship observed between increasing soil moisture and surface hardness. Future studies examining the relation between soil moisture and surface hardness and soil moisture and shear strength should focus on examining more than simple linear relationships that may exist with soil moisture.

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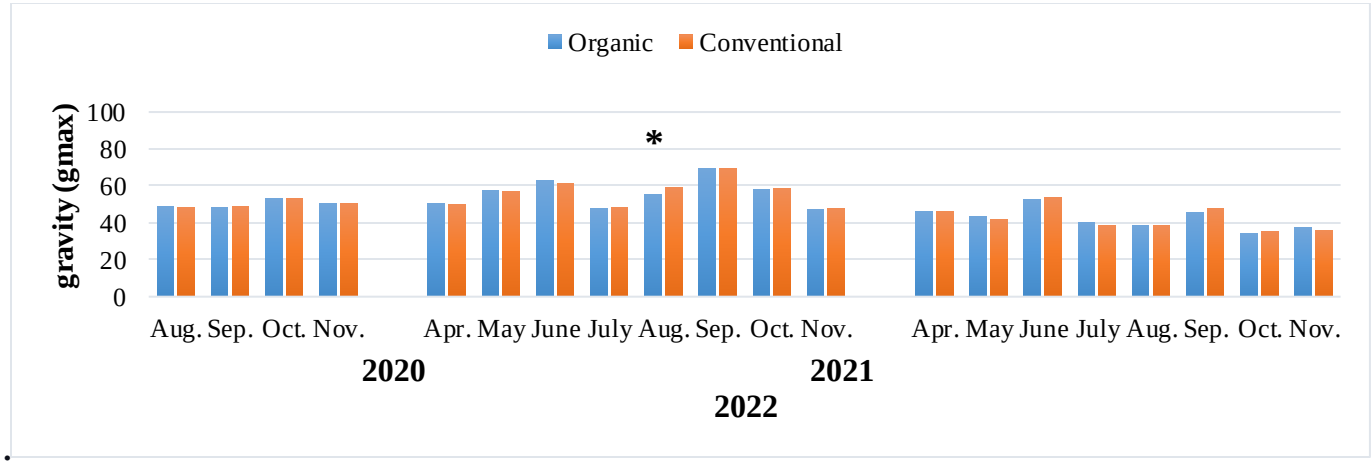

B.

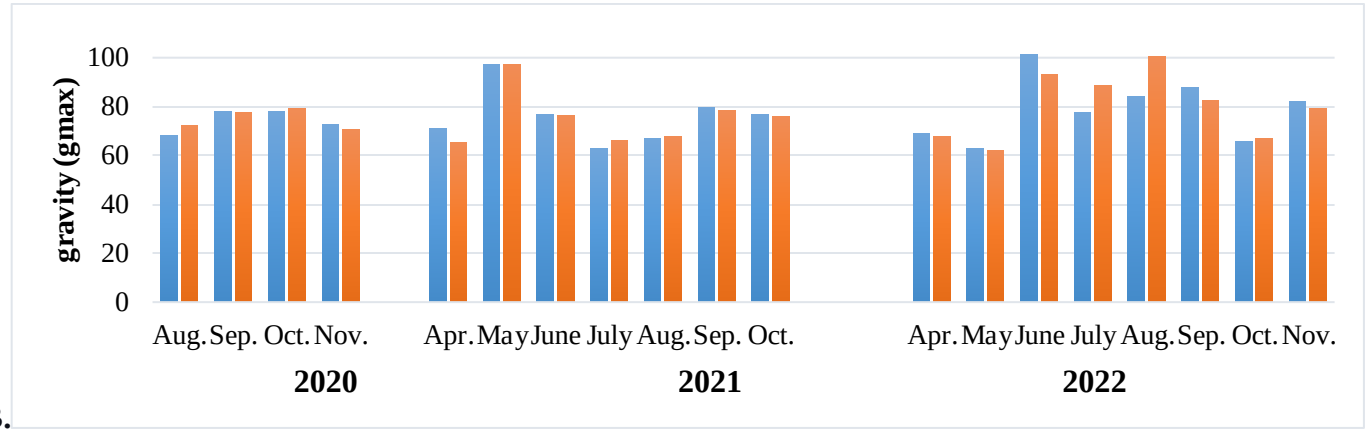

Figure 11: Clegg hammer surface hardness values at - PBTRF (A) and Laytonia Park (B) for organic and conventional management treatments in 2020, 2021, and 2022. Paired monthly histograms having a "*" above the pair indicate the two treatments are significantly different from one another at the P = 0.05 level.

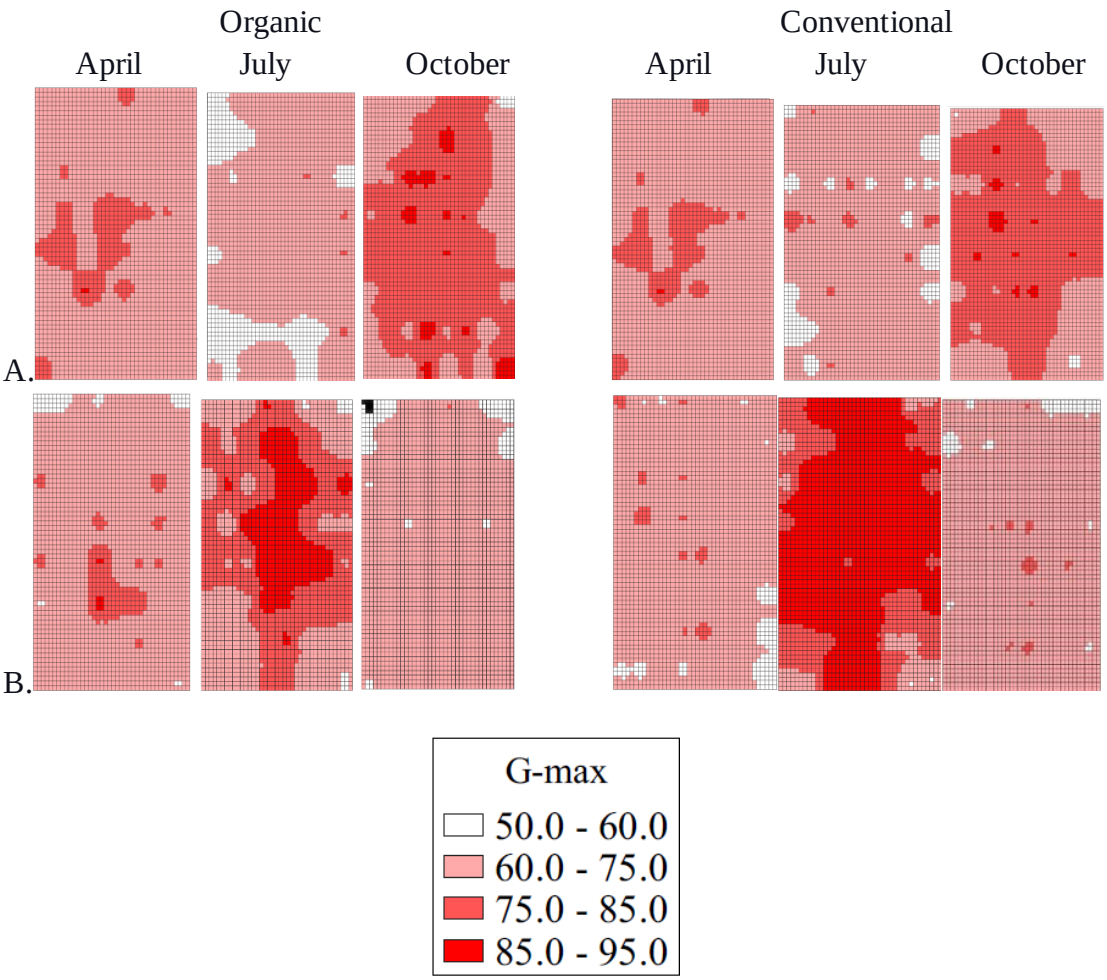

Figure 12: Spatial maps for surface hardness of the conventional and organically managed athletic fields at Laytonia Park in 2021 (A) and 2022 (B).

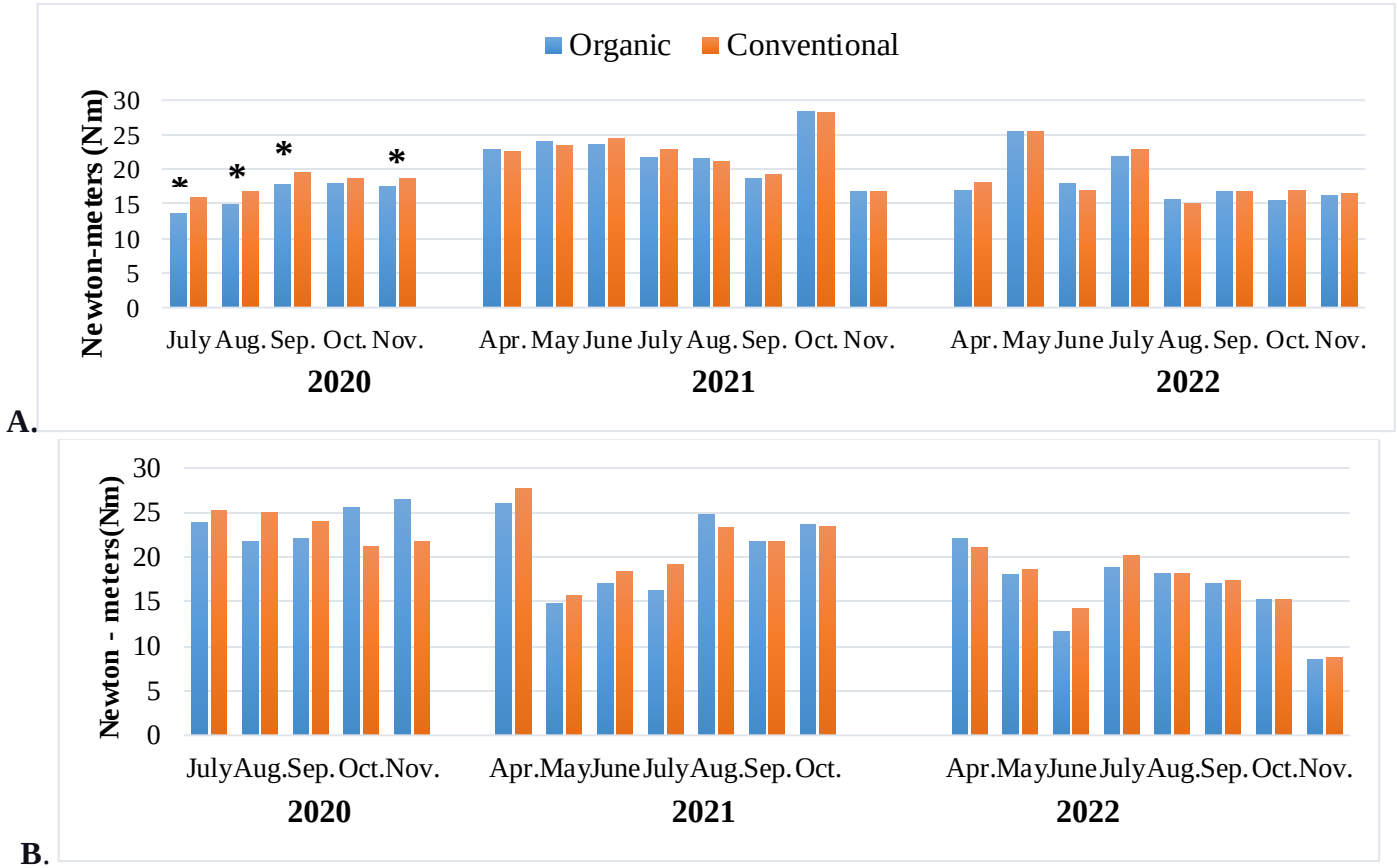

Figure 13: Shear strength at the PBTRF (A) and Laytonia Park (B) for organic and conventional management treatments in 2020, 2021, and 2022. Paired monthly histograms having a "*" above the pair indicate the two treatments are significantly different from one another at the P

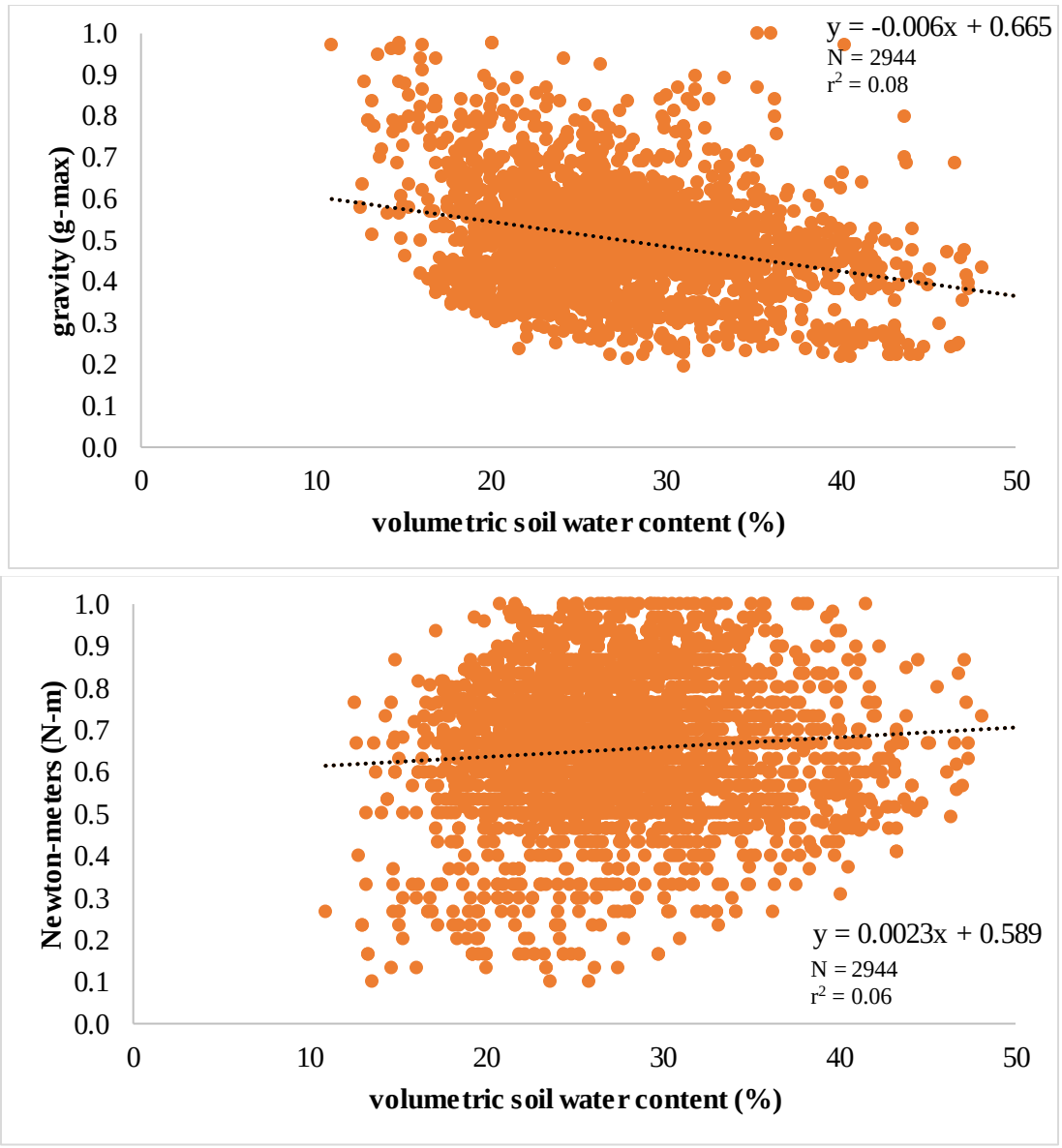

Figure 14: Relationships between surface hardness (g-max) and volumetric water content and shear strength (Newton-meter) and volumetric water content, where x is the equation is volumetric water content.

Table 7: Turfgrass CIST descriptive statistics for the months of April, July, and October in 2021 and 2022 for Organic and Conventionally managed athletic fields at Laytonia Park.

Year	Month	Treatment	Minimum	Maximum	Range	Mean	Standard deviation
2021	April	Organic	61	87	26	71.2	5.71
		Conventional	56	80	24	65.3	4.44
	July	Organic	42	77	35	62.8	7.46
		Conventional	43	85	42	66.2	9.39
	October	Organic	51	99	48	76.9	9.77
		Conventional	54	95	41	76.1	8.85
2022	April	Organic	54	93	39	69.1	7.30
		Conventional	53	82	29	67.9	6.85
	July	Organic	52	110	58	77.5	13.8
		Conventional	58	137	79	88.7	16.64
	October	Organic	46	76	30	65.7	5.79
		Conventional	51	79	28	67.0	6.41

Chapter 5: Describing the Rhizosphere of Organically and Conventionally Managed Athletic Fields

Introduction

Rhizosphere microbiomes are defined as the collection of microorganisms living together and interacting in the soil under the influence of plant roots, many of which are believed to be involved in plant growth and soil health. These microbes include fungi, bacteria, nematodes, archaea, protozoa, and algae, which may have beneficial or harmful effects on plant growth (Lynch, 1990; Berg, 2020). This collective group of microorganisms are also referred to as the soil food web. The complex interactions that occur in the rhizosphere microbiome (i.e., microbes of influence in and around the root zone) are crucial for plant health, productivity (Chaparro et al., 2012, Schnitzer et al., 2011), disease resistance (Raajimakers et al., 2009), in addition to biotic and abiotic stresses (Dubey, 2019). The concentration of rhizosphere microbes is also known to be influenced by the composition of root exudates, which are essential factors in determining the interactions between soil, microbes, and root (Badri et al., 2009a; Micallef et al., 2009). Rhizosphere microorganisms such as Proteobacteria, Firmicutes perform different functions (Kogel et al., 2006; Qiang et al., 2012) such as antagonism, resource competition (Hacquard et al., 2017; Kwak et al., 2018) to protect the plants against pathogens. For example, ectomycorrhizal fungi acidify the soil and covers the feeder roots to provide

protection against soil-borne pathogens (Tedersoo et al., 2020). Therefore, having a rhizosphere microbial community is a principal factor for plant growth and health.

Rhizosphere microbial communities can be impacted through management practices. Organic and conventional management operations have previously been shown to affect the soil microbiome (Cerecetto et al., 2021). For example, Lupatini et al., (2016) reported that organically managed farming systems had higher phylogenetic richness, and diversity when compared to conventionally managed wheat, potato, and maize cropping systems. Koberl et al., (2020) observed a decrease in microbial abundance in herbicide-treated soils compared to non-herbicide-treated ones. The regular use of herbicides has led to the humus degradation over the years and increased bacterial feeding. Some research proved that organic management practices could alter the soil's microbial population. Tritordeum (a novel hexaploidy cereal) has shown an increase in the rhizosphere microbial populations in organic farming conditions compared to conventional, particularly the Bacteroidetes phylum, which has beneficial effects such as greater root length, root surface area and number of root tips per plant leading to increased plant growth and health (Visioli et al., 2020). Similarly, a long-term field study done by Hartmann et al., (2015) demonstrated that soils of organically managed winter wheat and grass clover have higher soil microbial richness (bacteria and fungi) than conventional systems. Also, the community diversity may be different based on the management practices; for example, the fungal community diversity for organic and integrated managed fields differed significantly whereas the species richness remained unaffected in vineyard

soils, where the management practices had been in place for 10 years (Hendgen et al., 2018). Herbicides used in conventional management kill the plants and influence the activity of soil microorganisms (Haney et al., 2002). For example, use of glyphosate on soybean reduced the enzyme activity and increased the fungal communities. The fungal populations developed under glyphosate treatment affected plant growth and biological processes of soil and rhizosphere (Kremer et al., 2007). Application of herbicides like glyphosate in high concentration to forest soils affected the microbial community structure by increasing total and culturable bacteria, bacterial: fungal biomass; and very little effect on fungal properties like hyphae, propagules, and PLFA markers (Rattcliffe and Busse, 2006). Hence, the organic and conventional management practices do have effect on the rhizosphere microbiome.

Research on rhizosphere microbiome in different turfgrass environments is limited. Berin et al., (2017) evaluated the microbiome in *Poa annua* turf throughout the growing season for one year and found that structure of bacterial and archaeal communities varied for different months irrespective of management practices. Additionally, Crouch et al., (2017) evaluated the bacterial community compositions in the rhizosphere microbiome of mature and renovated turfgrass at three locations and observed no significant difference in the turfgrass microbiomes across the locations. Doherty and Roberts studied the effect of chemical and biological management practices on rhizosphere microbial communities in creeping bentgrass putting greens for two years and concluded that there was no significant difference in bacterial communities diversity and relative abundance between the two treatments

(2021). Further research to examine turfgrass rhizosphere microbiomes is needed, along with attention to athletic field turfgrass management.

The use of organic and conventional management practices has significant impacts on microbial communities in sports turf management (Li, 2019). However, little is known about the differences in the quantity of rhizosphere microbiome between organic and conventional management practices in athletic fields. It is also essential to understand how to determine the rhizosphere microbiome. Even though there are numerous techniques used, Next Generation Sequencing (NGS) or high throughput sequencing (HTS) are considered as the most advanced and sophisticated culture-independent techniques (Igiehon and Babalola, 2019) as it has the advantage of being very convenient to use (Liu et al., 2012). Traditionally for high throughput sequencing data, Operational Taxonomic Units (OTU's) are considered standard units (Berg et al., 2020). However, Amplicon Sequence Variants (ASV's) replaced the OTU's for their greater comprehensiveness, reusability, and reproducibility (Callahan et al., 2017). The bioinformatic analysis to clearly expresses the sequence data obtained from high throughput as the sequence data is biased and not standardized (Berg et al., 2020). At this time of this writing, NGS for microbiome has not been used in a field trial study for comparison of organic and conventional management athletic fields. Accordingly, the objective of this investigations was to evaluate temporal changes in the rhizosphere microbiome between organic and conventionally managed athletic fields.

Materials and Methods

The study was conducted from September 2019 to September 2022 at the University of Maryland Paint Branch Turfgrass Research Facility (PBTRF) in College Park, MD (Latitude 39.0071^0 N, Longitude 76.9408^0 W). The field plot site at PBTRF consisted of a 15 cm, 80:10:10 sand: soil: compost mix cap overlying a native soil having partially functioning title drainage system at a depth of approximately 2m. The soil cap had a pH of 6.3, 450 mg kg^{-1} P, 122 mg kg^{-1} K, and possessed 0.6% soil organic matter. Tahoma 31 bermudagrass (*Cynodon dactylon* x *Cynodon transvaalensis* 'OKC 1131') springs were broadcast at PBTRF on 22 August 2019 at an unknown rate.

Management practices and Trail Design

The purpose of this research was to examine full management programming on the developing turfgrass microbiome. To understand these components, the PBTRF site included eight plots each of 7.6 m by 9.2 m size with 13 cm buffer space between the plots. Treatment plots received year-round management programs designed as organic and conventional, which were replicated 4 times and arranged in a randomized complete block design. The entire experimental site was mowed at 2.5 cm three times per week, irrigated as needed to prevent drought stress, and overseeding consisting of 390 kg ha^{-1} of intermediate ryegrass (*Lolium hybridum*) in early October of each year of the study. Cultivation practices consisted of aerification using a Redexim Verti Drain (Redexim, 427 W Outer Road Valley Park, MO 63088), having 1.9 cm diameter solid tines spaced 13 cm apart which penetrated to depth of

10 cm. Decomposition to a depth of 15 cm was done using IMANTS Shockwave (Imants BV, Turnhoutseweg 29, 5541 NV Resusel, NL). Slice aerification using Universal AERO-vator (1st products Inc., 164 Oakridge Church Rd, GA 31794) was performed at 10 cm apart to depth of 4 cm. Solid tine aerification was performed to a depth of 10 cm using 18 mm tines with 5 cm by 5 cm of spacing.

Treatment programs (i.e., organic vs conventional) included variations in nutrient source and pesticides used to control noxious pests in the region. First, nutrient management was altered according to organic or conventional programming, but target amounts included 195 N ha^{-1} yr^{-1}, no P, and 151 K ha^{-1} yr^{-1} (organic) to 155 K ha^{-1} yr^{-1} (conventional) during the growing season for three successive years. Organic fertilizers included Nature Safe 10-0-8, Nature Safe 9-0-9, Fert-Nitro Plus Plant Nitrogen Amino Acid, and corn gluten meal while conventional fertilizers included Country club 24-0-12, potassium sulfate, and Andersons 22-0-22 containing 65% of N as Methylene urea. Organic programming plots also received soil health products such as raw seaweed concentrate (Trade name: Nature Essence Kelp), and Horticultural molasses. Preemergence weed control included the use of corn gluten meal or oxadiazon (Ronstar, Bayer Environmental Science) within organic or conventional managed areas, respectively. Post emergence weed control was limited to a single annual application of iron HEDTA (i.e., Fiesta Turf Weed Killer (Neudorff North America) or thiencarbazone-methyl + foramsulfuron + halosulfuron-methyl (i.e., Tribute Total, Bayer Environmental Science) to organic or conventional program areas respectively. Programming for fungal and insect pests was designed as

early curative control, Other than in fall of 2019, when a preplanned application of Velista (Penthiopyrad) was made in the conventional management program and Civitas (mineral oil) in the organic management program neither program received fungal or insect control measures during the course of this study.

Sampling and Extraction

Soil samples were collected from both treatments using a 20 mm diameter soil auger at a depth of 7.5 cm. Individual plots were divided into four quadrants, and representative samples (16 cores) were collected within each quadrant. Collected soil samples were placed in air-tight polythene bags and stored at -20 C prior to DNA extraction. Soil samples were collected in September 2020, May & September 2021. Sub-samples collected from individual quadrants in each plot were pooled together prior to DNA extraction. Soil samples were cleaned to remove debris and roots, prior to DNA extraction using the DNeasy PowerSoil Pro (Qiagen USA) kit, following the manufacturer protocol. Each extraction used 250 mg of pooled soil.

Amplicon Sequencing

Extracted eDNA quality and quantity were measured using a Nanodrop 1000 (Thermo Fisher Scientific, Waltham, MA) and a Qubit fluorometer (Life Technologies, Grand Island, NY). Following quantification, DNA samples were diluted to 1.5 ng/µL. The amplicons were generated using a two-step PCR process. PCR primers used for the initial PCR process included bacterial-16S and fungal ITS. The bacterial PCR primers used are Ba9F/Ba515mod1 primer pairs, whereas ITS3_KYO2-F/ITS4-R primer pairs are used as fungal PCR primers. The PCR

reactions were completed using MangoTaq DNA Polymerase (BioLine, Taunton, MA) in 25 µL volume containing 0.2 mM of each dNTP (BioLine), 2 mM MgCl2 (BioLine), 5X PCR buffer (BioLine), and 10 mM of each primer which were added to 2 mM of each sample containing eDNA. Conditions for PCR cycling included initial denaturation at 94 C for 2 min, followed by 30 cycles of 94 C for 1 min, 52 C for 45 sec, and 72 C for 45 sec, plus a final extension of 72 C for 5 min (Beirn et al., 2016; Doherty, 2018). The PCR used was QIAxcel Advanced System (QIAGEN, Gaithersburg, MD) i.e., with Thermal cycler. Following initial PCR, samples were cleaned and purified using ZR-96 DNA Clean and Concentrator -5 (Zymo Research, Irvine, CA).

Index reactions were set up at 40 mM volume, included 5 mM of each Nextera index primer (Illumina), 0.2 mM of each dNTP (BioLine), 2 mM MgCl2 (BioLine), 2.5 U MangoTaq DNA Polymerase (BioLine) and 5X PCR buffer (BioLine). Indexing reactions were performed on the same QIAxcel instrument 72 C for 3 min, 95 C for 30 sec, subsequently 12 cycles of 95 C for 10 sec, 55 C for 30 sec, 72 C for 30 sec, and a final step of 72 C for 5 min (Berin et al., 2016; Doherty, 2018).

Generated libraries were purified by using High Prep PCR (MagBio Genomics, Gaithersburg, MD) where targeted sequence fragments less than 200 bp were removed. The DNA libraries were normalized to 4 nM, and a pooled amplicon library (PAL) was formed for sequencing. To increase the sequencing, run diversity PhiX control (Illumina) was added, per manufacturer recommendations for amplicon/low diversity sequencing. Equal volumes of 0.2 M NaOH, PhiX and 4 nM

PAL were denatured at room temperature for 5 min, diluted to 10 pM, heat-denatured at 95 C for 5 minutes, and loaded for sequencing on an Illumina MiSeq platform. Amplicons were sequenced as paired end reads of 2 x 300 on MiSeq Reagent kits v2. The output for all the sequences was delivered in FASTQ format.

Sequence Analysis

Non-biological sequences were removed using the cutadapt program 1.9.1 (Martin, 2011). Resulting sequence data was imported into R programming, for processing using the DADA2 1.6 package (Callahan et al., 2016), for joining the relevant reads, denoising, inferring amplicon sequence variants (ASV's), and taxonomy assignment. Mitochondria, chloroplast, or archaea sequences were removed from the analysis. Low-quality bases were removed from the bacterial reads based on sequence quality profiles. Taxonomy was assigned using the Green-Gene database v.13.8 (McDonald et al., 2012) for bacteria and UNITE general FASTA release v.7.2 (Koljalg et al., 2013) for fungi.

Alpha diversity and Shannon and Simpson diversity index were performed with the given samples within the phyloseq R package. Kruskal-Wallis tests were performed to understand the difference in alpha diversity between the samples. Kruskal-Wallis tests were done with Benjamini-Hochberg correction for multiple-pairwise comparisons using dunn.test package in R (Dinno, 2017). Bray-Curtis dissimilarities were determined using the R package phyloseq (version 4.2) as a measure of beta diversity (Gardener, 2014). The sequence reads were subjected to beta diversity for understanding differences for bacterial and fungal communities

between the two management treatments. Principal Component Analysis was done using Bray-Curtis dissimilarities. Pairwise permutation tests were performed along with PERMANOVA.

The statistical analyses were performed using R statistical computing environmental version 3.4.2 (R core team, 2017). All the images/graphics were created using ggplot2 (Wickham, 2016).

Results and Discussion

To begin, only forward reads of the bacterial 16S were used for analysis as reverse reads exhibited poor quality offering minimal overlap. The total ASV count after quality filtering was 9205, of which 8281 were bacteria, and 924 were fungi. The bacterial ASVs primarily consisted of Proteobacteria, Bacteroidota, Actinobacteriota, and Planctomycetota, at 21%, 9%, 7%, and 7%, respectively, at the phylum level (Table 7). Twelve percent of bacterial ASVs were unidentifiable below the kingdom level.

Relative abundance of bacteria and fungi. The relative abundance of the bacterial communities had minimal changes/fluctuations throughout the experiment between organic and conventional treatments (Figure 15). The unclassified bacterial phyla accounted for ~12%. Among the classified bacterial communities, Proteobacteria, Bacteriodiota, and Actinobacteriota were the predominant phyla regardless of management practices with a relative abundance of 21%, 9%, and 7% respectively (Table 7). Additional studies have shown that wheat microbiomes commonly possess the same dominant bacterial phyla (Ofek et al., 2014; Gdanetz and

Trail, 2017). In turfgrass, another study by Beirn et al., (2016) identified Proteobacteria and Acidobacteria as the predominant bacterial phyla for *Poa annua* putting greens. The lack of differences between organic and conventional management regimes in this work is consistent with previous research in Ithaca, NY for organic and conventional management of maize inbred fields, which did not result in markedly different microbial communities (Peiffer et al., 2013). However, Visioli et al., (2020) concluded that Tritordeum adapted better to organic farming compared to the conventional because of the increase in the rhizosphere community, especially Bacteroidetes phylum and Alphaproteobacteria and Gammaproteobacteria showed higher relative abundance even though the individual bacterial ASVs were predominant in Proteobacteria.

The fungal ASVs were principally composed of the Ascomycota, Basidiomycota, Rozellomycota, and Chytridiomycota with 47%, 20%, 9%, and 8%, respectively, at the phylum level. At class level, the fungal communities were primarily made up of Dothideomycetes and Sordariomycetes (Figure 16). The relative abundance of the Dothideomycetes class of fungi was highest ~0.5 to 0.7% in 2021 compared to 2020. Sordariomycetes fungi relative abundance was highest at ~0.3 to 0.4% during the experiment (In 2020) compared to the second year at ~0.2 to 0.3% (In 2021). Additional studies have found similar fungal classes predominant in the rhizosphere microbiome. For example, the organic and conventional management fields of wheat with different crop rotations consisted of Dothideomycetes, Leotiomycetes, and Sordariomycetes in their rhizosphere microbiome (Lenc et al.,

2015; Gdanetz and Trail, 2017). Another study done by Kembel and Mueller, (2014) at low land rainforest areas for 57 tree species, found Dothideomycetes, Eurotiomycetes, and Sordariomycetes as the dominant fungal communities among phyllosphere fungi. Sorodariomycetes, the second predominant class (20%) in this study has a possible effect on plant health promotion and fighting plant diseases because Trichoderma is one of its members. For example, *Trichoderma harzianum* strain 1295-22 reduced the disease severity of *Rhizoctonia solani*, *Pythium graminicola* in turfgrass areas (Lo et al., 1997). The class Eurotiomycetes was found only in 2020 regardless of the management practice (Figure 16). It was interesting to observe that Mortierellomycetes and Mucoromycetes were detected only during September, irrespective of the year (Figure 16). Dothideomycetes was one of the abundant class in the phylum Ascomycota have a potential advantage of combating pathogenic taxa and is the most dominant fungal taxa in plant compartments. Previous research shows that Dothideomycetes have a diverse range of fungi including epiphytes, endophytes, and plant pathogens and relative abundance is most sensitive to plant developmental stages (Xiong et al., 2021). Also, Dothideomycetes which is considered as saprophytic fungi, helps in nutrient cycling (Adams, 2013). In the current study, there are fluctuations in the fungal communities observed for different dates and very minimal fluctuation observed between the organic and conventional treatments. The relative abundance of the fungal communities varied and/or fluctuated for different dates. This can be due to the different time/months of the year where the microbiome activities are different. For example, Chaparro et al.,

2014 studied the bacterial communities in Arabidopsis thaliana at different stages of growth and found that diversity and composition of rhizosphere bacterial communities were different at seedling stage compared to flowering and bolting stages of the plant. This indicates the fluctuations in the microbiome depending on the time of the year.

Drivers of Alpha Diversity. The experimental run showed significant differences for the dates (Sep20, May21, and Sep21) for bacterial ($p = 0.002$) and fungal ($p = 0.002$) alpha diversity. Bacterial diversity was lowest for Sep 2021, having no significant difference between the treatments (Table 10). The highest diversity of rhizosphere bacterial communities was observed for Sep 2020 followed by May 2021. This means that the bacterial diversity decreased with time. The Alpha diversity for fungal communities showed the highest diversity measure for Sep21 with variability in the species abundance from organic to conventional management programs. Similar variability in the species was observed in Sep20. The Kruskal-Wallis chi^2 tests revealed a significant difference was observed for dates for bacterial ($p = 0.002$) and fungal ($p = 0.002$) communities. However, within the dates, the experimental run showed they were not significant for individual dates (data not shown). No data exist for turfgrasses, but compared to other crops, a different pattern of significance was seen for the rhizosphere microbiome of Chinese chives (*Allium tuberosum*). The alpha diversity analysis did not reveal any significant differences for bacterial and fungal communities over one, two and five years of cropping systems (Gu et al., 2020).

Our data did not support the hypothesis that management systems would have an impact on the turfgrass microbiome. Throughout the current study, no significant difference was observed between organic and conventional treatments at any point. This could be due to the fact that the research plots were newly established (i.e., <3 years) and more time is required for observing the significant differences among the management practices. Hartmann et al., (2015) studied the diversity of bacterial and fungal communities of farming systems of >20 years and concluded organic farming has increased richness and diversity of soil microbiota compared to conventionally managed fields of winter wheat and grass-clover. In the current study, not much fluctuation was observed in the diversity of bacteria and some fluctuation in fungal communities was observed. A similar result was documented in the microbial communities of pine forests, cultivated and livestock pasture lands. They concluded that the bacterial and fungal communities did not significantly differ across the land-uses and different land-use types did not necessarily have different soil fungal or bacterial communities (Lauber et al., 2008).

Drivers of Beta Diversity. The permutational multivariate analysis of variance (PERMANOVA) analysis showed a significant difference for the dates for bacterial (R^2 = 0.381, p = >0.0001) and fungal (R^2 = 0.402, p = >0.0001) communities. This means that 45% and 43% of the bacterial and fungal community variability, respectively, could be explained by sampling date. However, the analysis was not significant for the organic and conventional treatments over the entire study period indicating there is variability in the species composition between the treatments.

The principle component analysis (PCA) plot showed that the centroids for bacterial and fungal communities were clustered based on the dates and not management practices (Figure 18 and 19). The fungal communities clustered more tightly than bacterial communities, which showed more heterogeneity among dates. The first two axes of the PCA plot could explain 45% and 44% of the variability in the bacterial (Figure 18) and fungal (Figure 19) communities data respectively. But there was no significant difference observed for the individual dates of the study i.e., Sep20, May21, and Sep21 (data not shown). The Dispersion testing did not show any significant differences over the whole experiment for organic and conventional management practices.

Conclusions

In conclusion, this study provides insights into the microbial communities present in the organic and conventional management of athletic fields. The results showed that bacterial and fungal communities did not have significant differences for the relative abundance of bacterial and fungal communities between the different management practices. The alpha and beta diversity for the rhizosphere bacterial and fungal communities showed that the sampling date was a stronger driver of microbial diversity. This means that while management practices may not influence the rhizosphere microbiome in the short term, environmental conditions present at different times of the year can drive shifts in the microbiome. These findings help in understanding the importance of soil microbiota in athletic field conditions under different management practices. However, further research is needed to investigate

the impacts of organic and conventional management practices on microbial communities for a long term of more than 5 years to identify the specific change in the microbial composition if any, which can support the sustainable management practices for athletic fields.

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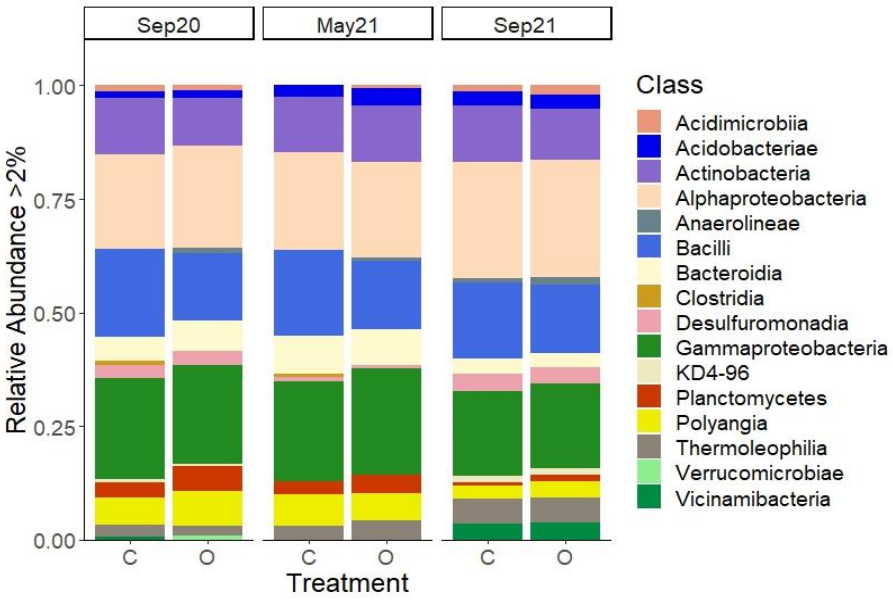

Figure 15: Relative abundance of bacterial taxa calculated using the phyloseq in R, of bacterial classes associated with bermudagrass grown at different management levels. “C”, and “O” refer to “Conventional”, and “Organic” management levels respectively.

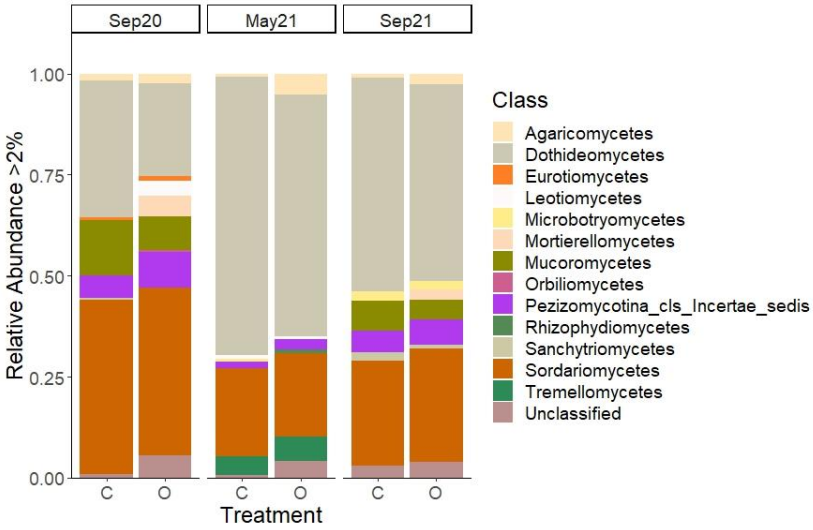

Figure 16: Relative abundances, calculated using the phyloseq in R, of fungal classes associated with bermudagrass grown at different management levels. “C”, and “O” refer to “Conventional”, and “Organic” management levels respectively.

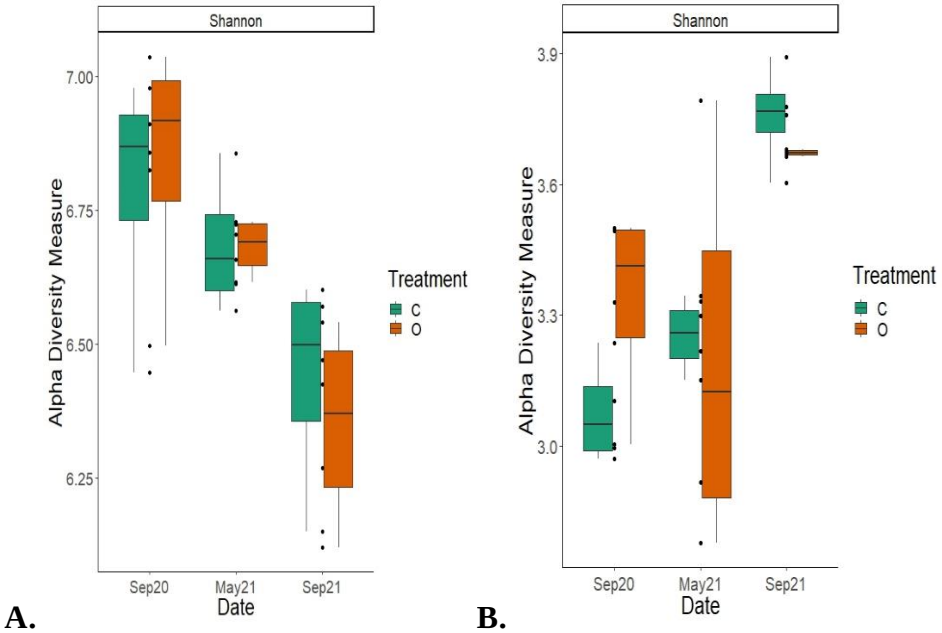

Figure 17: Shannon diversity measures for bacterial (A), fungal (B) communities, calculated using phyloseq in R associated with different management levels of study. Higher values indicate higher overall species richness and evenness. Orange points indicate outliers.

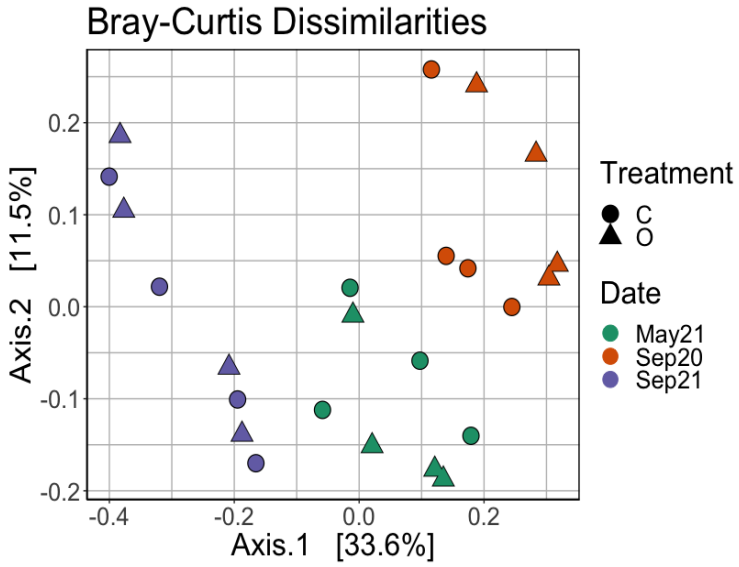

Figure 18: Principal component analysis of bacterial data, completed using phyloseq in R, of Bray-Curtis distance matrices, calculated in phyloseq of bacterial communities of the experimental run. Values in brackets indicate percent variation explained.

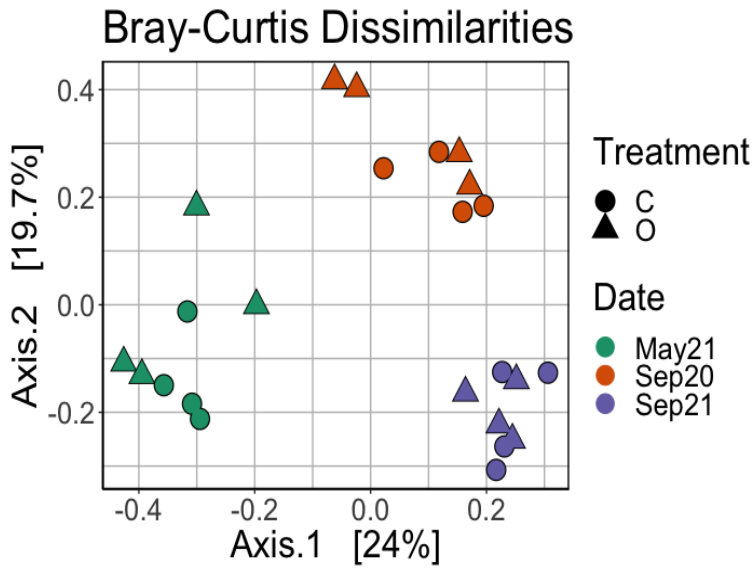

Figure 19: Principal component analysis of fungal data, completed using phyloseq in R, of Bray-Curtis distance matrices, calculated in phyloseq of fungal communities of the experimental run. Values in brackets indicate percent variation explained.

Table 8: Composition of Bacterial Amplicon Sequence Variants

Phylum	ASV's Assigned	Percent of ASVs
Proteobacteria	1741	21.02
NA	1002	12.10
Bacteroidota	790	9.54
Actinobacteriota	658	7.95
Planctomycetota	612	7.40
Firmicutes	542	6.55
Myxococcota	445	5.37
Verrucomicrobiota	442	5.33
Acidobacteria	440	5.31
Chloroflexi	418	5.05
Patescibacteria	266	3.21
Bacteroidota	190	2.29
Bdellovibrionota	154	1.86
Gemmatimonadota	134	1.62
Desulfobacterota	102	1.23
Dependentiae	89	1.07
Cyanobacteria	77	0.93
Elusimicrobiota	27	0.33
Nitrospirota	22	0.27
RCP2-54	21	0.25
Abditibacteriota	17	0.21
Deinococcota	12	0.15
NB1-j	11	0.13
Spirochaetota	11	0.13
Sumerlaeota	11	0.13
MBNT15	10	0.12
Zixibacteria	8	0.09
Armatimonadota	7	0.08
WPS-2	5	0.06
Halanaerobiaeota	4	0.05
Dadabacteria	3	0.04
Campilobacterota	2	0.02
DTB120	2	0.02
WS2	2	0.02
Ciliophora	1	0.01
FW113	1	0.01

TX1A-33	1	0.01
WS-1	1	0.01

Table 9: Composition of Fungal Amplicon Sequence Variants

Phylum	**ASV's Assigned**	**Percent of ASVs**
Ascomycota	438	47.40
Basidiomycota	189	20.45
Rozellomycota	84	9.09
Chytridiomycota	79	8.55
Mortierellomycota	41	4.44
Blastocladiomycota	24	2.60
Glomeromycota	16	1.73
Mucoromycota	15	1.62
Aphelidomycota	11	1.19
Basidiobolomycota	10	1.08
Monoblepharomycota	9	1.00
Neocallimastigomycota	3	0.32
Olpidiomycota	3	0.32
Zoopagomycota	2	0.22

Table 10: Alpha Diversity for microbial communities of Organic and Conventionally treated athletic fields

	Shannon Index			
	Bacteria		**Fungi**	
	Krushal-Wallis chi^2 test	p-value	Krushal-Wallis chi^2 test	p-value
Date	12.125	0.0023	12.285	0.0022
Treatment	0.003	0.954	0.1633	0.6861

Table 11: Beta Diversity for microbial communities of Organic and Conventionally treated athletic fields

	Bacteria		**Fungi**	
	PERMANOVA p-value	R^2	PERMANOVA p-value	R^2
Date	0.000999***	0.381	0.000999***	0.402

Treatment	0.5744	0.251	0.441	0.322

Chapter 6: Conclusions

Public concerns about the use of pesticides in the management of athletic fields has resulted in a growing interest in the use of natural or organic based management programs. In this thesis the comparative abilities of a conventional and organic management program to provide uniform natural grass surface conditions was examined by evaluating the turfgrass quality, surface hardness, rotational shear of bermudagrass athletic fields and research plots managed as an athletic field playing surface. It was found that except for differences in weed encroachment and the removal of overseeded ryegrass, the two management programs provided similar levels of turfgrass quality throughout most of the year. The organic program consistently resulted in higher spring turfgrass quality because of the earlier use of fertilizer and the avoidance of the use of a preemergence herbicide (oxadiazon) that removed ryegrass. Lower turfgrass quality was frequently observed on athletic fields when compared to research plots and was attributed to the extensive amount of play the athletic fields received which ranged from 699 to 1040 hours of yearly play in second and third years of study.

Over the entire study period, there were no consistent effects observed between the organic and conventional treatments for the surface hardness values on athletic fields or at research plot site indicating management treatment had little effect on surface hardness. The athletic fields surface hardness readings were higher than the research plots for all the three years of study period regardless of management

practice and again was the result of the extensive play that occurred on athletic fields in comparison the research plots. In the case of the latter, where simulated traffic was limited to biweekly simulated traffic for three of months years and only in the latter two years of the investigation. In the examination of athletic field surface properties, it was found that the relationship between soil moisture and surface hardness, and soil moisture and shear strength was moderately weak.

An examination of spatial and temporal changes in turfgrass quality and surface hardness for the two management regimes at the athletic field sites revealed that spatial variability across the fields was greatest in July in two of the three years data was collected with higher surface hardness, lower turf quality being observed in-front of goals and in mid-field face-off areas. With the exception of one spatial analysis evaluation date, similar spatial patterns in turfgrass quality and surface hardness were observed on athletic fields managed using the two different approaches.

This thesis also examined the ability of the USGA's TruFirm meter to predict clegg hammer surface hardness using data collected from athletic fields, research plots, and golf course putting greens with and without consideration of the volumetric water content at time measurements were collected. The effect of play was also examined by partitioning the data int time periods sites received no play or simulated traffic because of the Covid-19 pandemic or post pandemic when play and simulated traffic on the research plots took place. Surface hardness on the greens was greater than it was on the research plots before traffic was introduced. However, mean greens

surface hardness was significantly lower than that obtained from research plots and athletic fields after traffic occurred at both sites. Results indicated that clegg surface hardness values can be predicted from TruFirm measurements on low greens with moderate degree of confidence ($r^2 = 0.71$) and with much greater uncertainty on trafficked athletic fields and research plots ($r^2 = 0.42$) when the turf was maintained at 2.5 cm, and when soil moisture is included as a second predictive variable. In the absence of athletic filed and research plot traffic, the TruFirm device was not able to predict Clegg surface hardness. The result of this study highlights the need to investigate the relationship between the two devices at various mowing heights.

Finally, this thesis examined how microbial communities may be influenced by the two management regimes at the research plots site. The results showed that bacterial and fungal communities did not have significant differences for the relative abundance of bacterial and fungal communities between the different management practices. The alpha and beta diversity for the rhizosphere bacterial and fungal communities showed significant differences for the different dates of sampling and did not show any significant differences for the treatment practices. This means that while management practices may not influence the rhizosphere microbiome in the short term, environmental conditions present at different times of the year can drive shifts in the microbiome. These findings help in understanding the importance of soil microbiota in athletic field conditions under different management practices. However, further research is needed to investigate the impacts of organic and conventional management practices on microbial communities for a long term greater

than the time it was examined with the current study to identify the specific change in the microbial composition if any, which can support the sustainable management practices for athletic fields.

Appendix

Table 1 - Date of application by year and location for chemical material that comprised organic and conventional management regime.

Management regime	Chemical treatment	Location								
		PBTRF					Laytonia			
		2019	2020	2021	2022		2019	2020	2021	2022
		Date of application								
Conventional	Ronstar @ 8 L ha^{-1}		21 Apr.	20 Apr.	22 Apr.			22 Apr.	30 Apr.	20 Apr.
Conventional	Country Club 24-0-12, 60% Mesa, 100% EXPO SGN 150 @ 39 kg N ha^{-1}		7 May	11 May	9 May			5 May	10 May	6 May
Conventional	Tribute Total @ 0.23 L ha^{-1}		1 Jun	1 Jun	1 Jun			2 Jun	7 Jun	3 Jun
Conventional	Ammonium Sulfate 21-0-0 @ 34 kg N ha^{-1}	24 Oct.	29 May	1 Jun	1 Jun		25 Oct.	3 Jun	2 Jun	1 Jun
			1 Jul.	2 Jul.	1 Jul.			3 Jul.	8 Jul.	6 Jul.
Conventional	0-0-50 @ 44 kg K ha^{-1}		1 Jun	4 Jun	7 Jun			8 Jun	8 Jun	7 Jun
			1 Jul.	2 Jul.	1 Jul.			3 Jul.	8 Jul.	6 Jul.

Conventional	Andersons 22-0-22, with 65% Methylene Urea @ 44 kg N ha^{-1}	6 Sep.	18 Aug.	18 Aug.	15 Aug.		10 Oct.	18 Aug.	23 Aug.	17 Aug.
			16 Sep.	15 Sep.	15 Sep.			14 Sep.	16 Sep.	16 Sep.
Organic	Nature Safe 10-0-8 @ 39 kg N ha^{-1}		8 Apr.	7 Apr.	11 Apr.			3 Jul.	14 Apr.	12 Apr.
Organic	Nature Safe 10-0-8 @ 24 kg N ha^{-1}	6 Sep.	1 Jul.	2 Jul	1 Jul.		10 Oct.		8 Jul.	6 Jul.
			16 Sep.	15 Sep.	15 Sep.			14 Sep.	16 Sep.	16 Sep.
Organic	Corn Gluten Meal 10-0-2 @ 24 N kg ha^{-1}	24 Oct.	21 Apr.	20 Apr.	22 Apr.		25 Oct.	22 Apr.	30 Apr.	20 Apr.
			May	11 May	9 May				19 May	6 May
Organic	Fiesta @ 0.4 L 1000 ft^2		1 Jun	1 Jun	1 Jun			2 Jun	7 Jun	3 Jun
Organic	Ferti-Nitro Plus Plant Nitrogen Amino acid 13.62-0-0 @ 5 kg N ha^{-1}		29 May	-	-			3 Jun	2 Jun	1 Jun
			1 Jul.	2 Jul.	1 Jul.			3 Jul.	8 Jul.	6 Jul.

Organic	Nature Safe 9-0-9 @ 24 kg N ha^{-1}		7 May	1 Jun	1 Jun			5 May	2 Jun	1 Jun
			18 Aug.	18 Aug.	15 Aug.			3 Jun	2 Jun	1 Jun
								18 Aug.	23 Aug.	17 Aug.
Organic	Nature Essence Kelp @ 0.2 L 1000 ft^2		1 Jul.	2 Jul.	1 Jul.			2 Jul.	6 Jul.	7 Jul.
Organic	Nature's wisdom horticultural molasses @ 0.02 L 1000 ft^2		1 Jul.	2 Jul.	1 Jul.			2 Jul.	6 Jul.	7 Jul.
Conventional and Organic	Cal-Turf Pro @ 2.3 kg product 1000 ft^2		18 Aug.	18 Aug.	15 Aug.			18 Aug.	23 Aug.	-

Conventional and Organic	Andersons Black Gypsum (21% Humic) @ 2.3 kg product 1000 ft^2	8 Oct.	2 Oct.	5 Oct.			18 Oct.	1 Oct.	1 Oct.	
Conventional and Organic	Sili-Cal SS @ 4.5 kg 1000 ft^2		28 Oct.	5 Oct.	-		21 Oct.	27 Oct.	1 Oct.	-

Table 2 - Date of application by year and location for cultivation treatments for organic and conventional management regime.

Management regime	Cultivation treatment	Location								
		PBTRF					Laytonia			
		2019	2020	2021	2022		2019	2020	2021	2022
		Date of application								
Conventional and Organic	Aerification – Redexim Vetridrain		9 Apr.	7 Apr.	11 Apr.		24 Oct.	7 Apr.	-	11 Apr.
			15 Sep.	15 Sep.	15 Sep.			14 Sep.	14 Sep.	16. Sep.
			16 Oct.	15 Oct.				-	18 Oct.	
Conventional and Organic	De-compaction IMANTS - Shockwave		5 May	27 May	9 May			5 May	13 May	5 May
			-	23 Jul.	27 Jul.			23 Jul.	27 Jul.	22 Jul.
Conventional and Organic	Slice aerification		28 May	10 Jun	1 Jun			28 May	1 Jun	1 Jun
			18 Aug.	23 Aug.	19 Aug.			19 Aug.	19 Aug.	15 Aug
Conventional and Organic	Core aerification with hollow tines		1 Jul.	1 Jul.	30 Jun			1 Jul.	6 Jul.	

Conventional and Organic	Verticutting		-	1 Jul.	8 Jul.			-	7 Jul.	5 Jul.
			-	18 Aug.	19 Aug.			-	17 Aug.	17 Aug.

Table 3 – Monthly dates of data collection by year and location.

Response variable	Date of collection															
	2020															
	PBTRF								Laytonia Park							
	7 Apr	7 May	9 Jun	9 Jul.	10 Aug	11 Sep	8 Oct	10 Nov	17 Apr	18 May	18 Jun	16 Jul	20 Aug	21 Sep	21 Oct	23 Nov
Turf Quality	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
NDVI	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Soil Moisture	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x
Hardness-Trufirm	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Hardness-Clegg					x	x	x	x					x	x	x	x
Shear Strength				x	x	x	x	x				x	x	x	x	x

Green color Index	x	x	x	x	x	x	x	x									
Ryegrass Count			x	x													
	2021																
	6 Apr	6 May	7 Jun	6 Jul.	6 Aug	8 Sep	8 Oct	8 Nov		14 Apr	20 May	17 Jun	13 Jul	13 Aug	15 Sep	15 Oct	16 Nov
Turf Quality	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
NDVI	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
Soil Moisture	x	x	x	x	x	x	x	x		x		x	x	x	x	x	x
Hardness-Trufirm	x	x	x	x	x	x	x	x		x	x	x	x	x	x		x
Hardness-Clegg	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	
Shear Strength	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	
Green color Index	x	x	x	x	x	x	x	x									
Crabgrass Count																	
Ryegrass Count																	
Thatch Thickness					x												

% Clover																	
	2022																
	11 Apr	5 May	6 Jun	18 Jul.	11 Aug	14 Sep	14 Oct	9 Nov		19 Apr	16 May	17 Jun	26 Jul	24 Aug	21 Sep	25 Oct	23 Nov
Turf Quality	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
NDVI	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
Soil Moisture	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
Hardness-Trufirm	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
Hardness-Clegg	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
Shear Strength	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
Green color Index	x	x	x	x	x	x	x	x								x	x
Crabgrass Count				x	x	x	x	x					x	x	x	x	x
Ryegrass Count		x	x	x	x	x	x	x								x	x
Thatch Thickness					x												
% Clover		x	x	x	x	x	x	x			x	x	x	x	x	x	x

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