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Achieving sustainable turfgrass management

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Introduction

Turfgrass is required to meet a challenging range of aesthetic, functional and environmental requirements, whilst also mitigating the threat of abiotic and biotic stresses which are being accentuated by climate change. The turfgrass industry is also facing increasing pressure to reduce its environmental impact and advance more sustainable maintenance practices that utilise and/ or optimise fewer agronomic-related resources. This volume summarises the wealth of recent research that addresses these challenges, whilst also identifying potential mitigation strategies to reduce the sector's contribution to climate change, such as reduced fertiliser use and water conservation.

The chapters are split into three parts: Part 1 chapters focus on the physiology, breeding and cultivation of turfgrass species, specifically focusing on breeding techniques, soil management, phosphite utilisation and irrigation and water management. Chapters in this part also draw attention to maintenance practices of turfgrass as well as advances in using turfgrass for athletics fields, sports pitches and ornamental lawns. Chapters in Part 2 review various biotic and abiotic stresses that affect turfgrass management, such as diseases, insect pests and weeds. Chapters also look at the importance of plant growth regulation, abiotic stress management, organic matter management and the use of biostimulants in turfgrass. Part 3 chapters provide case studies on various management practices for turfgrass, such as the use of unmanned aircraft systems, methods for selecting turfgrass varieties and cultivars as well as water management and soil testing.

Part 1 Physiology, breeding and cultivation

The volume opens with a chapter that focuses on understanding turfgrass physiology. Chapter 1 first begins by discussing physiological responses to four of the most common abiotic stress conditions: drought, heat, freezing and salinity stresses. The chapter reviews the importance of understanding how turfgrasses respond to drought, heat, freezing and salt stress, highlighting the historical perspectives and recent advances in each form of stress. The chapter also emphasises how these stresses damage plants and how in turn plants respond to tolerate these conditions. Sections on emerging issues and future directions for research for each form of stress are also provided.

The next chapter focuses on advances in breeding for improved cultivars of turfgrass. Chapter 2 draws attention to major cool-season species such as bentgrass, fine and tall fescue, Kentucky bluegrass and perennial ryegrass. It focuses on major warm-season species such as bermudagrass, buffalograss, seashore paspalum, St. Augustinegrass and Zoysiagrass. For each species, the chapter discusses biological characteristics, traditional breeding strategies, current breeding objectives and advanced breeding methods for the major cool- and warm-season turfgrass species. Emerging challenges and future potential areas to develop research in are also highlighted.

The subject of Chapter 3 is advances in soil management for successful establishment and maintenance of turfgrass. It first explores soil physical properties relevant to turfgrass management, focusing specifically on soil texture, compaction, water-holding capacity and structure. The chapter then moves on to examine soil chemical properties relevant to turfgrass management, such as sodicity and plant-available nutrient content. This is then followed by an analysis of some of the most well-known soil biological properties crucial for turfgrass management, drawing specific attention to nitrogen availability and the importance of the soil microbiome. The chapter concludes by identifying areas for future study in soil management for turfgrass species.

Chapter 4 focuses on advances in phosphite utilisation for turfgrass. The chapter begins by first describing the chemical structure of both phosphate and phosphite and how the differences between them can affect their use as a nutrient source in plants. It moves on to review the use of phosphite in turfgrass and how it is an emerging nutrient source and is considered in some cases, controversial. The chapter goes on to examine how phosphite can be used as a source of phosphorus nutrition and highlights how it can be incorporated into turfgrass nutrition strategies. A section on disease control in turfgrass via phosphite is also included, before concluding with an overview of the importance of expanding currently available research in phosphite use in turfgrass management.

The next chapter looks at advances in irrigation and water management of turfgrass. Chapter 5 reviews the importance of estimating turfgrass water needs. With this in mind, the chapter moves on to examine advances with sprinkler devices and technologies as well as the importance of using subsurface drip irrigation as an alternative way to provide turfgrass with water. The chapter also provides alternatives to potable water and highlights several turfgrass management practices that can also reduce water needs, such as mowing, fertilisation, soil surfactants and plant growth regulators. This then leads into the next section, which focuses on the use of plant growth regulators in turfgrass management. The chapter also highlights the use of soil surfactants in turfgrass to manage soil hydrophobicity.

The subject of Chapter 6 is advances in maintenance practices of turfgrass. It begins by highlighting the importance of maintaining turfgrass quality through the use of mowing, drawing specific attention to various technologies and maintenance strategies such as autonomous mowers, vertical mowing and grooming. The chapter moves on to examine putting green management, looking at aspects such as cultivation practices, rolling and firmness measurement. A section on turfgrass renovation is also provided, focusing on elements such as weed control, seed bed preparation, non-chemical control and other plant and soil issues that can occur during turfgrass renovation. The chapter also reviews the use of turf colourants and highlights how their application can be a useful tool for maintaining turfgrass.

Chapter 7 examines advances in turfgrass breeding and genetics for the purpose of athletic fields and sports pitches. The chapter first discusses the most appropriate types of species and cultivar for this, focusing on how improvements can be made to both warm-season and cool-season turfgrass. The chapter then discusses the different methods that can be used in order to improve the sports field's quality, such as alternative root zone amendments, seed coating and seed germination covers, hybrid turfgrass systems and thick cut sod. A section on sports field maintenance is also provided, drawing attention to aspects such as cultivation, topdressing, irrigation, grow lights and cooling fans as well as painting techniques. The chapter also reviews performance testing and site specific management.

The final chapter of Part 1 addresses the advancements in turfgrass for ornamental lawns. It first focuses on breeding and selection advances, drawing attention to consumer lawn preferences and the implications this can lead to in terms of contemporary breeding and production, as well as discussing the current breeding and selection trends for ornamental turfgrass lawns. The chapter then moves on to review various management practices, such as soil preparation, planting and establishment, fertilisation and nutrient management, mowing and cultivation and irrigation and water management. A section on non-traditional or alternative lawns is also provided, which is then followed by a review of socioenvironmental research practices to advance sustainable lawn management.

Part 2 Biotic and abiotic stresses

Part 2 opens with a chapter that covers advances in turfgrass disease management. Chapter 9 begins by first introducing one of the most destructive diseases of cool-season turfgrasses, anthracnose. The chapter first highlights how this disease’s severity is influenced by plant nutrition, mowing, irrigation and sand topdressing and how it is crucial to develop these management practices to decrease the effect and occurrence of anthracnose in cool-season turfgrass. The chapter moves on to address dollar spot, a disease that affects all turfgrass species and how cultural management practices can provide more effect management of dollar spot. The presence of Microdochium patch and snow moulds are also touched upon, followed by brown patch, large patch and root diseases of turfgrasses. A section on host resistance is also included, a recently developed disease management strategy for turfgrass ecosystems. This is then followed by an overview of fungicide management, in particular, the previously addressed dollar spot. The chapter concludes by highlighting where future research developments should turn their attention to.

Moving on from Chapter 9, Chapter 10 addresses the advances in turfgrass insect pest management. It starts by first reviewing the recent studies of major turfgrass insect pests, such as annual bluegrass weevil, bill bugs, white grubs and fall armyworm. The chapter then moves on to discuss recent studies on emerging turfgrass pests, focusing specifically on European crane flies and *Chaetocnema minuta*. A section on integrated pest management practices is also provided, drawing attention to methods such as pest detection and monitoring, chemical control, insecticide resistance and non-target issues with chemical insecticides. The chapter also discusses biological control, cultural control, host plant tolerance and resistance to pests and the use of plant growth promoting rhizobacteria.

The next chapter focuses on advances in turfgrass weed management. Chapter 11 discusses relevant and recent developments in synthetic herbicides, alternatives to synthetic herbicides and non-chemical strategies for weed management including cultural, physical, and genetic approaches. Advances in integrated weed management strategies and barriers preventing adoption of integrated weed management strategies are also discussed. Opportunities for research and development to improve integrated weed management are presented throughout.

Chapter 12 examines advances in plant growth regulation in turfgrass. It begins by providing an overview of the current use of growth regulators in both cool-season and warm-season turfgrass species. It then goes on to discuss enhancing rooting and establishment as well as turfgrass wear tolerance. A section on seed head suppression and production is also included, which is then followed by an overview of the suppression and control of annual bluegrass. Enhancing disease tolerance and tolerance to environmental extremes such as cold and drought are also discussed. Shade tolerance enhancement is also reviewed and a case study on how turfgrass species and light quality can determine the effectiveness of using plant growth regulators for shaded turf is also included.

The subject of Chapter 13 is advances in abiotic stress management in turfgrass. Commonly observed abiotic stresses in turfgrass systems include drought, high temperature, low temperature, low irradiance, traffic, salinity, and chemical phytotoxicity. Managing abiotic stresses with reduced irrigation, fertilizer, energy, and pesticides has become critical to the sustainability of the turfgrass industry. The chapter first describes how sustainable strategies and practices can be implemented to manage abiotic stress, focusing specifically on managing turfgrass growth, moderating the environmental conditions causing the stress, improving abiotic stress tolerance and masking abiotic stress through methods such as colourants. It moves on to discuss ways of detecting abiotic stress and how data-driven decision-making can be used to manage it.

Chapter 14 focuses on advances in managing organic matter in turfgrass ecosystems. The chapter begins by first discussing the effects of organic matter on turfgrass, then moves on to review how organic matter can be monitored and measured. It then discusses the relationship between organic matter and turfgrass diseases, focusing on how different levels of organic matter can increase or decrease the development of major diseases such as dollar spot. The chapter also draws attention to soil microbial populations can affect organic matter content.

The final chapter of Part 2 addresses the advances in biostimulants in turfgrass. Chapter 15 reviews the use of biostimulants in turfgrass management. It first identifies the different types of biostimulants that can be used for turfgrass, focusing on phytohormones, biopolymers, protein hydrolysates and other nitrogen-containing compounds, botanical and synthetic bioactive compounds. The chapter also highlights the possibility of using humic substances, organics, inorganics/minerals, biologicals/microbials, soil surfactants and other naturally derived or synthetic bioactive compounds.

Part 3 Case studies

The first chapter of the four case study chapters in this section focuses on the use of unmanned aircraft systems in turfgrass monitoring. Chapter 16 begins by providing a brief overview of light reflectance by plants and how this can be used by sensors to assess how well a plant can utilise this for photosynthesis. The chapter moves on to emphasise the importance of mission planning in terms of using these systems, specifically indicating that defining the target of interest, how much resolution is required to identify patterns via an image, selecting the appropriate sensor and aircraft are all crucial elements to this process. Flight planning and data collection frequency are also deemed important as well. It also reviews data processing considerations and provides examples of small unmanned aircraft system applications in turfgrass.

Chapter 17 discusses selecting turfgrass varieties and cultivars, using the National Turfgrass Evaluation Program (NTEP) as a basis for the chapter's discussion. The chapter first describes the factors that impact turfgrass sustainability, then moves on to highlight how the data collected from using the NTEP can be used to select appropriate cultivars. An overview of the updated NTEP database is also provided, which is then followed by six case studies demonstrating ways of selecting sustainable cultivars via the use of the NTEP. These case studies include: identifying a geographical region, the use of seasonal analysis, choosing appropriate site characteristics, identifying key sustainability factors, locating and comparing cultivars and finally, the advanced selection of cultivars with improved drought resistance.

Chapter 18 examines the potential relationship between turfgrasses and pollinators. The chapter begins by first considering how land use change and pollinator decline correlate with one another, specifically drawing attention to the drastic change in human population which in turn, has resulted in the need to significantly change the landscape. The chapter then considers how the presence of pollinators can be influenced by this changed landscape, followed by a section that considers using urban grasslands as sources of pollinator habitat and forage. This is then followed by a review of the various plants that can be used as part of turfgrasses for pollinator habitats, again, a case study is provided to support the discussion. The chapter also reviews the management of pollinator friendly mixtures, focusing specifically on how turfgrass management practices such as mowing and the use of pesticides need to adapt in order to support pollinators. A section on the additional considerations that also need to be taken into account when preparing turfgrass for pollinator species is also included.

The next chapter considers the management of water for turfgrass in arid environments. Chapter 19 first reviews the importance of soil moisture for turfgrass, focusing on methods to improve moisture uniformity such as deep watering, soil moisture monitoring, supplemental irrigation and the use of wetting agents. Several case studies are provided to emphasise the importance of water and irrigation management, the first three focus on how turfgrass conversion can result in significant water savings. The next two draw attention to the use of native grasses and alternative plant materials following turfgrass removal. The use of subsurface drip irrigation on golf courses is also discussed.

The final chapter of the book looks at using soil testing in turfgrass management. Chapter 20 addresses how soil testing can be used to analyse soil types, it first highlights the common soil test extractants used, such as Bray P1 and P2, Mehlich 1 and 3, Olsen (also known as sodium bicarbonate), Morgan, Lancaster, ammonium acetate and diethylenetriaminepentaacetic acid. The chapter also includes discussion on the use of monocalcium phosphate and saturated paste extract, before moving on to highlight how soil test calibration can be used as a basis for fertiliser recommendations. A case study in sustainable soil test interpretation is also included.

Acknowledgements

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Chapter 1

Advances in understanding turfgrass physiology

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1 Introduction

From a highly managed and well-manicured golf course putting green to a low-input right-of-way, turfgrasses must cope with a wide range of environmental extremes, which frequently fall outside of optimal growing conditions. These challenging environments can alter a plant's basic physiology, negatively impacting growth and development, and eventually result in the death of turf areas. Unfortunately, there is reason to believe that in the coming future environmental conditions in which turfgrasses are grown will only become more challenging. Global climate change is estimated to raise air temperatures by more than 2°C, and beyond elevated temperatures, and there is expected to be more extreme weather patterns of every sort, from floods to droughts (IPCC, 2021). Further compounding these issues is an increasing need to reduce inputs applied to turf areas for both environmental and economic reasons. This is particularly true of water resources, which are increasingly limited and in competition for demand from other users, but is also true of fertilizers, pesticides, and even the labor needed to implement cultural management practices.

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The development of more sustainable turfgrasses relies on a better understanding of plant physiological response to stressful conditions, which includes determining how plants are damaged from specific stresses and the mechanisms employed to protect and prolong survival under stress. In turn, this information will help inform best turfgrass management practices, identify traits to integrate into advanced cultivars, and ultimately leverage new technologies that allow for the continuing use of functional green spaces despite these environmental challenges. This chapter will examine four of the most detrimental abiotic stress that turfgrasses commonly encounter (i.e. drought, heat, freezing, and salinity stresses) and which are expected to increase in duration or severity in the future.

2 Drought stress

2.1 Overview and significance of drought stress in turf

Turfgrasses are a major component of urban green spaces throughout the world. In addition to esthetic, recreational, and functional benefits, turfgrasses offer many important ecosystem services which benefit humans and the environment (Beard and Green, 1994; Chang et al., 2021). However, in regions where rainfall is not adequate to meet plant demand, turfgrasses may require supplemental irrigation to maintain acceptable quality and function. Although the exact acreage of irrigated turfgrass in the USA is not known, total turfgrass acreage has been estimated to be 30 million acres, making it three times larger than any other single irrigated crop (Milesi et al., 2005). In more arid parts of the USA, more than 50% of residential water usage is sometimes devoted to landscape irrigation (Degen, 2007; Haley et al., 2007; Mayer et al., 1999). Based on conservative estimates by Cabrera et al. (2013), total water use by golf courses combined with landscapes in Texas represented 47% of the total use within the urban/municipal water sector and 13% of the total annual demand by all activities, positioning urban irrigation as the state's third largest water user behind agriculture and other urban uses.

In recent years, water conservation has become a major priority for many municipalities, driven largely by urban population growth combined with periodic droughts (WHO, 2020). While urban landscapes have traditionally been comprised predominantly of turfgrass, municipalities and water purveyors are increasingly providing homeowners monetary incentives to remove turfgrass and replace it with alternative 'water-efficient' landscapes utilizing native or locally adapted alternative plant species (Addink, 2005; Pincetl et al., 2019). Another water conservation strategy employed by water purveyors is mandatory irrigation restrictions, which may limit residential landscape irrigation to a given day of the week or, under more extreme measures, restrict irrigation once every 2 weeks or less (Hejl et al., 2021). In addition to residential irrigation restrictions, larger turf sites such as golf courses or athletic fields are also commonly forced to deal with reduced water allocations imposed by water purveyors as a means of meeting water conservation goals (GCSAA, 2015). When this occurs, turf managers must prioritize water to critical areas such as greens and tees or impose deficit irrigation on larger acreage areas such as fairways in order to meet or remain in compliance with water allocation goals. For turfgrasses to remain a sustainable component of future urban green spaces, they must be capable of providing functional surfaces with significantly less water in the form of rain or irrigation than in the past and, at times, surviving extended periods of prolonged drought.

Considering the importance and widespread use of turfgrasses in the modern landscape and growing need for water conservation, turfgrass drought resistance has become a trait of major importance within the industry. As a result, a substantial amount of plant physiological research and breeding efforts are currently being devoted to this issue. The following is intended to provide a review of the current understanding of turfgrass drought resistance while highlighting recent advances which have improved our knowledge in this area.

2.2 Historical perspectives, recent advances and future direction with drought stress research in turf

Drought develops when root zone soil moisture becomes insufficient to support turfgrass water demand. Therefore, drought is most common during periods of high evapotranspiration and low rainfall or inadequate irrigation. The ability of turfgrass plants to resist drought, termed drought resistance, is a broad classification involving one or multiple drought-resistance mechanisms, including avoidance, tolerance, or escape.

2.3 Drought avoidance in turfgrasses

Drought avoidance is considered to be the most widely employed drought-resistance mechanism among turfgrasses (Levitt, 1980). Avoidance is characterized by the ability of a turfgrass plant to maintain favorable internal water potential and normal physiological function during drought, primarily by minimizing transpiration and/or maximizing water uptake. Turfgrass species noted for possessing superior drought-avoidance characteristics include tall fescue [*Lolium arundinaceum* (Schreb.) SJ Darbysh.], bermudagrass [*Cynodon dactylon* (L.) Pers.], buffalograss [*Bouteloua dactyloides* (Nutt.) J.T. Columbus], and bahiagrass (*Paspalum notatum* Flueggé) (Fry and Huang, 2004).

Considering nearly 98% of water uptake by turfgrass roots is lost to transpiration through leaves, species and cultivars capable of minimizing

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