Turfgrass and Climate Change

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ABSTRACT
Climate change is occurring and is impacting biological systems through increased temperatures, more variable precipitation, and increased CO₂ in the atmosphere. These effects have been documented for agricultural species, primarily grain crops, pasture and rangeland species. The extension of these relationships to turfgrass has been limited; however, these plants are an important part of our ecosystems and preservation of these plantings adds to social value and ecosystem services. Turfgrasses can be divided into cool-season and warm-season species and the projected changes in maximum air temperatures, along with increased root zone temperatures may promote a Northward migration of warm-season turfgrasses. Increased spring precipitation and more variable summer precipitation coupled with more intense precipitation events are projected to occur requiring enhanced management of soil water. Turfgrass management to ensure adequate root zone soil water, and the selection of varieties or species with greater drought tolerance in the warmer regions will be necessary to preserve turfgrass plantings. Increases in CO₂ benefits turfgrass growth and positively affects water use efficiency, which decreases the potential effects of a more variable precipitation regime because of impacts on soil water use. Genotypic variation in response to soil water deficits provides a foundation for screening turfgrass species to adapt to climatic stresses. Changes in temperature and precipitation variation will increase the potential for abiotic and biotic stresses on turfgrasses. Turfgrass management will require increased attention to increased abiotic and biotic stresses.

Core Ideas
• Climate change will affect temperature and precipitation patterns.
• Increasing temperatures will cause a shift in turfgrass species to more northern climates.
• Variation among varieties of turfgrass provide opportunity to increase climate resilience.
• Climate change will increase abiotic and biotic stresses on turfgrass.

Climate impacts on biological systems have the potential to disrupt phenological cycles and physiological responses of plants, animals, insects, and diseases. Changes in temperature, precipitation, humidity, solar radiation, and CO₂ expected to occur over the next 30 to 40 yr will affect biological systems; however, not all to the same degree. One aspect of climate change that is often understated is that future variations will not be uniform in either space or time, and require a more localized view of the impacts than broad, general statements. This will have large implications for how we consider and evaluate the impacts of climate change on turfgrasses. There is a large body of information on climate impacts on agriculture assembled by the Intergovernmental Panel on Climate Change (IPCC), and several recently published summaries have further documented the impact of a changing climate on agricultural systems (Walthall et al., 2012; Hatfield et al., 2014; Melillo et al., 2014; Porter et al., 2014); however, these have not concentrated on potential effects on turfgrasses.

Changes in plant growth are not simply a direct function of climate, but from the interaction of climate with different soil factors such as soil organic matter, soil fertility, erosion, irrigation, fertilizers, and biotic stresses (insects, diseases, and weeds). The interaction of soils with climate change has the potential to increase the vulnerability of plants to climate change because of the effect of soil degradation on soil water availability and nutrient cycling (Hatfield, 2014).

A comprehensive analysis of climate impacts on agricultural and horticultural crops by Hatfield et al. (2011) and on pasture and rangeland by Izaurralde et al. (2011) showed temperature and precipitation as major factors affecting plant growth and production. All plants require temperatures within their range for development and growth, and each species has their own specific temperature range. Cool-season turfgrasses have an optimum temperature range between 15 and 24°C, whereas warm-season turfgrasses have an optimum between 27 and 35°C (DiPaola and Beard, 1992). This temperature range determines where these grasses are grown; however, growth is dependent on seasonal precipitation. The ability of soils to provide adequate soil water and nutrients to crops is the foundation for climate resilience, and the integration of climate and soils will determine survivability and economic viability of turfgrasses.

Climate Change
Climate change encompasses all aspects of change in the mean, range, and extreme of temperature and precipitation. Current changes in climate increases the probability in the
frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events because of shifts in the distributions of these variables (Hansen et al., 2012). Hansen et al. (2012) showed that shifts in the distribution of temperature or precipitation may lead to the increased occurrence of extreme events. A continued change in temperature and precipitation will potentially contribute to increased problems of water availability to plants. Across the continental United States we can define mid-latitudes as the range between 30 and 45° N while high latitudes are between 45 and 60° N and this definition is used in this analysis. Turfgrass management strategies to offset pressures created by climate change have largely yet to be developed.

Temperature

Current climate change scenarios that examine temperature effects are more certain, and evident. In the near term, temperatures are projected to increase the global average by 1 to 1.5°C from 2016 to 2035 as compared to the 1850 to 1900 period (Kirtman et al., 2013). Winter temperatures are projected to increase more than summer temperatures and near term increases in seasonal mean and annual mean temperatures are expected to be larger in the tropics and subtropics than in mid-latitudes (Kirtman et al., 2013). For the United States, temperature records have increased between 0.50 to 0.75°C over the 1970 to 1999 period compared to the 1890 to 1970 period (Walsh et al., 2014). However, this increase has not been uniform across the United States (Melillo et al., 2014). Coupled with regional variation is seasonal variation, with temperatures increasing more in the winter than the summer. This has increased the frost-free period in the Midwest by 9 d (1991–2012) as compared to 1901 to 1960. Additionally, there is the potential of an additional 30 to 40 d of frost-free conditions in 2070 to 2099, when compared to the 1970 to 2000 period (Walsh et al., 2014). Changes in maximum temperatures for January and July for 2020 and 2090 predict major increases across the United States for the remainder of this century, and suggest that variation will persist across the United States in both near term and by 2090 (Fig. 1). The scenarios used for these assessments were based on no change in the trajectory of the CO₂ for the remainder of the century with minimal mitigation efforts and represent the most extreme conditions expected in temperature and precipitation patterns. Across the upper Midwest, July maximum temperatures may increase from 30 to 35°C and in the southern United States average July temperatures are projected to exceed 40°C. A similar trend is projected for minimum temperatures in January and July across the same time period, with increases of 3 to 4°C over a 70-yr period (Fig. 2). Warmer minimum temperatures are projected to move Northward in the 21st century with the greater change in the spatial distribution of minimum temperatures in January compared to July (Fig. 2).

The changing amplitude of temperature patterns show an interesting characteristic, where minimum temperatures are increasing, while maximum temperatures show less of an increase, or even a decline. Increasing concentrations of greenhouse gases and water vapor in the atmosphere cause a reduction in the re-radiation of energy from the surface at night, affecting nighttime temperature changes (Walsh et al., 2014). Changing temperature patterns reveal greater increases in the winter than in the summer, leading to a longer frost-free period and potentially earlier onset of growth in the spring of perennial plants and a longer growing season (Fig. 2).

Precipitation

Two general trends are suggested in the precipitation signal: (i) an expected increase in annual precipitation, and (ii) a shift in the seasonality of precipitation. In the near term, Kirtman et al. (2013) project an increase in precipitation in the high to mid-latitudes, with concurrent increases in evaporative demand and specific humidity. In the long-term climate projections, Collins et al. (2013) stated that precipitation would increase concurrent with the increasing temperatures at a rate of 1 to 3% per 1°C change in temperature due to an increase in water vapor pressure. Increases in atmospheric water vapor are a result of increased evaporation from the earth’s surface due the increasing temperatures (Collins et al., 2013). Of even more importance is the projected increase in spatial variation with a greater difference between wet and dry seasons. Projected increases between wet and dry seasons suggest an increased variation within seasons and among years. Over this century, days with precipitation greater than 25 mm d⁻¹ has increased with further projections of days with more than 25 mm d⁻¹ to continue to increase with the greatest occurrence of these extremes in the southern and western mountain ranges of the United States (Fig. 3). This change in the climate signal is already evident through increased flooding and droughts across the United States in the past 20 yr (Walsh et al., 2014). Projections for the United States show changes in seasonality with more spring precipitation across the higher latitudes coupled with decreasing summer precipitation. There is a projected increase in January precipitation from 2020 through 2090 across all of the United States, except for the extreme South (Fig. 4). Conversely, July precipitation is projected to decrease across the Great Plains and southern states, with the overall trend toward decreasing precipitation (Fig. 4).

CLIMATE IMPACTS ON TURFGRASSES

Turfgrasses are grown throughout the United States primarily in urban environments as part of the overall landscape. The effects of climate change on grasses grown for pasture or range have been detailed in a review by Izaurralde et al. (2011). In this paper, the focus is on perennial turfgrasses and how climate change may affect their growth and survival.

Temperature Impacts

Each turfgrass species has a specific temperature range characterized by an upper and lower threshold and an optimum temperature. The thresholds for different crop species have been summarized by Hatfield et al. (2011). In general, increases in temperature caused by climate change will affect phenology and growth. Increasing temperature will speed the rate of phenological development. Cool-season grasses such as creeping bentgrass (Agrostis stolonifera L. ‘Penncross’), fine fescue (Festuca spp.), tall fescue (Schedonorus arundinaceus (Schreb.) Dumort.; syn. Festuca arundinacea Schreb.), Kentucky bluegrass (Poa pratensis L.), annual ryegrass (Lolium multiflorum L.), and perennial ryegrass (Lolium perenne L.) occupy the northern United States, while warm-season turfgrass species,
Fig. 1. Projected January and July maximum temperatures for 2020 and 2090 for the United States using the RCP 8.5 scenario. Data downloaded from Climate Explorer (https://toolkit.climate.gov/climate-explorer2).
Fig. 2. Projected January and July minimum temperatures for 2020 and 2090 for the United States using the RCP8.5 scenario. Data downloaded from Climate Explorer (https://toolkit.climate.gov/climate-explorer2).
Fig. 3. Projected days with greater than 25 mm of precipitation for the United States. Data downloaded from Climate Explorer (https://toolkit.climate.gov/climate-explorer2).
Fig. 4. Projected monthly precipitation for January and July across the United States with the RCP 8.5 scenario. Data downloaded from Climate Explorer (https://toolkit.climate.gov/climate-explorer2).
for example, bahiagrass (*Paspalum notatum* L.), hybrid bermudagrass (*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Davey), carpetgrass (*Axonopus compressus*), St. Augustinegrass (*Stenotaphrum secundatum* (Walter) Kuntze), and zoysia spp. (*Zoysia* spp.) are grown in the southern United States. Given the projected change in temperature shown in Fig. 2, we would expect the transition zone between cool-season and warm-season grasses to progress Northward during the 21st century; however, any change would represent an interaction between temperature and precipitation. The interactions between temperature and precipitation prevent the development of an exact estimation of the changes in the distribution of turfgrass species.

Temperature responses of turfgrasses have been summarized by DiPaola and Beard (1992) and characterize chilling and high temperature stresses as being detrimental to turfgrass growth. The differences between cool- and warm-season grasses in response to temperature extremes is illustrated in Fig. 5. Projections of climate change have the potential to shift the temperatures for a given location to a warmer regime; however, plant response to temperature has remained the same. This will create a condition with a greater likelihood of exposure to higher temperatures during the growth period. In grasses, the tillering response is critical and Beard (1973) stated that maximum tillering occurs at temperatures slightly below the optimum shoot growth temperature. As temperature increases, both cool- and warm-season grasses are more likely to experience conditions in which tillering could be reduced. The potential warming of soil temperatures has the potential to increase soil temperatures above the optimum root temperatures of 10 to 18°C for cool-season species and above 24 to 30°C in warm-season species (DaCosta and Huang, 2013). They cautioned that given the projections for temperature increases coupled with the potential for extreme events, there is the likelihood for more heat stress on both cool- and warm-season species. The chances of exceeding optimum temperatures increase for both shoot and root functions, creating a condition in which cool-season grasses will progress farther North because their survivability will decrease in the central latitudes of the United States being replaced by warm-season grasses (Fig. 5). The interplay between root temperatures and air temperatures in the physiological reactions of grasses reveal that exposure to high root temperatures reduces shoot growth, photosynthesis, root viability, and increases senescence (DaCosta and Huang, 2013). Heat stress reduces root number, root length, and root biomass and increases root mortality, which in turn affects the ability of the plant to extract water and nutrients from the soil (Huang et al., 1998, 2001; Huang and Gao, 2000; Xu and Huang, 2000a, 2000b, 2001a, 2001b; Sweeney et al., 2001; Huang and Liu, 2003; Liu and Huang, 2005).

Temperature stresses will not be isolated to only high temperature stress. Chilling stress occurs when temperatures are below the optimum (Fig. 5) and can be a factor in the management of warm-season species. Projections for climate change do not exclude the increased chance of extreme temperatures at the low end of the temperature range. Even though there is an increase in the frost-free period, the probability of frost has not changed (Walsh et al., 2014). Bertrand et al. (2013) summarized the effects of low temperature on turfgrass and stated that low temperature tolerance is one of the factors affecting the distribution of grasses. Injury caused by low temperatures affects the survival of different species and quality of the stand in the spring (Gusta et al., 1980; Karnok and Beard, 1983; Bertrand et al., 2013). Responses of turfgrasses to local microclimates will be affected by topography, elevation, southern exposure, or shading from buildings or trees (Hulke et al., 2008; Bertrand et al., 2013). Microclimatic conditions can offset or accentuate the effects of climate for a specific region and illustrate the complex nature of the interactions in developing general statements about the impact of climate change.

**Fig. 5.** Temperature responses of cool-season and warm-season turfgrass. Adapted from DiPaola and Beard (1992).
Soil Water Impacts

The increasing variability in precipitation will increase the likelihood of periods during the growing season in which soil water is limiting for optimum turfgrass growth. Management of soil water given the changes in precipitation intensity, seasonality, and amounts will ensure that turfgrass has adequate soil water supply or the soil is not saturated and has adequate drainage. As summarized by Kopp and Jiang (2013) different species of turfgrass have a range of water requirements. A comparison study of four turfgrasses by Fu et al. (2004) revealed that Kentucky bluegrass required soil water availability in the root zone of near 100% of field capacity, while tall fescue and bermudagrass produced acceptable quality with 40 to 60% of field capacity to meet evapotranspiration requirements. Differences among years were attributed to differences in the evaporative demand, suggesting an interaction with air temperature and humidity variation among growing seasons. Physiological responses to soil drying between Kentucky bluegrass and tall fescue revealed that an adaptation mechanism to water stress was to reduce shoot respiration rates (Huang and Fu, 2000). The range of survival mechanisms to cope with water shortages, included changes in allocation of C to roots to develop deeper rooting systems. These responses to soil water supply vary among species, with shoot growth and leaf water status exhibiting the largest response in warm-season, deep-rooted species such as buffalo grass [Bouteloua dactyloides (Nutt.) Engelm.], centipedegrass [Eremochloa ophiuroides (Munro) Hack.], and seashore paspalum (Paspalum vaginatum Swartz.). Shallow-rooted species, for example, zoysiagrass and bermudagrass were more sensitive to water stress (Wherley et al., 2014). Threshold inducing changes in transpiration rates of warm-season grasses varied among species and varieties within a species (Carrow 1996a, 1996b; Cathey et al., 2011; Fuentealba et al., 2016). The primary factors causing this difference were evapotranspiration rate, soil texture (soil water holding capacity), and depth of the rooting system. Zhang et al. (2017) compared 14 genotypes from St. Augustinegrass [Stenotaphrum secundatum (Walt.) Kuntze], Japanese lawngrass (Zoysia japonica Steud.), manillagrass [Zoysia matrella (L.) Merr.], and bermudagrass (Cynodon dactylon (L.) Pers.) to conclude there was no consistent mechanism for drought tolerance among these entries. Xin et al. (2013) suggested that screening turfgrass species for water use efficiency and drought resistance using a combination of phenotypic studies (morphology, growth rate, and cell physiology), gene quantitative trait loci (QTL) mapping for the morphological and physiological characteristics of different species, and quantifying the understanding of the molecular mechanisms of water use efficiency in turfgrass would provide a path toward breeding genotypes to withstand drought stress. Ebdon and Kopp (2004) demonstrated the value of different physiological techniques to screen turfgrass germplasm for drought tolerance. The results presented by Fuentealba et al. (2016) demonstrated differences among genotypes to show the potential for screening to cope with water shortages. Providing these assessment of turfgrass species for drought tolerance is an effective adaptation strategy for the increased variability of precipitation during the summer period. Seasonality shifts in precipitation create the potential for excess water in the spring when evaporative demand is low and plants are commencing growth. This is exacerbated in soils with poor drainage (Kopp and Jiang, 2013). Improving the soil to maintain aggregate structure for improved aeration would be beneficial in poorly drained soils or in areas with increased spring precipitation. Management of the soil under perennial turfgrasses to enhance both infiltration and aeration could provide benefits for surviving excess and deficit soil water conditions.

Carbon Dioxide Impacts

Atmospheric concentrations of CO₂ are projected to reach 450 μmol mol⁻¹ by 2050, and to exceed 700 μmol mol⁻¹ by the year 2100 (Collins et al., 2013). Plants respond positively to increases in atmospheric CO₂ with increased growth and improved water use efficiency (Hatfield et al., 2011). Creeping bentgrass response to increased CO₂ (400 vs. 800 μmol mol⁻¹) exhibited a faster growth rate of lateral stems and increased shoot and root dry weights with reduced specific leaf area (Burgess and Huang, 2014). Net photosynthetic rates increased, along with reduced stomatal conductance and transpiration rate which improved water use efficiency with a greater effect in C₃ compared to C₄ species. The combined effect of improved water use efficiency and improved growth will enhance growth and survival under water limited conditions. Coupling these observations with the findings from Ebdon and Kopp (2004) and Fuentealba et al. (2016) suggest genetic variation in water use efficiency of turfgrass species could be evaluated as a strategy to cope with climate change. Increased CO₂ effects on water use efficiency would increase the number of days a perennial grass could maintain non-limiting transpiration, thereby, making more efficient use of water in the soil profile. This would reduce exposure to potential drought stress for a perennial grass, which will become increasingly important in water-limited environments or with more variation in summer precipitation.

Turfgrass stands have the potential to mitigate climate change by sequestering C and reducing greenhouse gas emissions from turfgrass stands. Bremer (2006) found nitrous oxide (N₂O) emissions were a function of N management practices with N rate being the primary factor related to emissions. There have been some recent assessments of the value of turfgrass stands to sequester C and through a modeling assessment for lawns, Zirkle et al. (2011) showed the potential sequestration rate varied between 25.4 to 204.3 g C m⁻² yr⁻¹ with variation among lawn management practices. Zhang et al. (2013b) utilized a simulation model, DAYCENT, to evaluate potential best management practices for lawns in Colorado to demonstrate how soil C, nitrate leaching, and water use could be managed in response to the changing temperature and precipitation conditions among growing seasons. Computer simulation models can be used to evaluate the potential for turfgrass management for N₂O emissions over the lifetime of a stand. Zhang et al. (2013a) found that emission rates would change throughout time and management could be adopted to maintain the viability of turfgrass to be a sink for greenhouse gases. The impact of turfgrass management on the C cycle offers a potential to change greenhouse gas emissions while enhancing the quality of turfgrass stands.
CLIMATE IMPACTS ON PESTS

The indirect impacts of climate change are associated with the biotic stresses, for example, weeds, insects, and diseases. High temperature or drought stress on turfgrass increases the potential for poor growth (Huang et al., 1998, 2001; Huang and Gao, 2000; Sweeney et al., 2001; Huang and Liu, 2003; Liu and Huang, 2005). This effect on growth could be further amplified if we combine the negative effects on the root physiology induced by the warmer soil temperatures (Xu and Huang, 2000a, 2000b, 2001a, 2001b; Liu and Huang, 2005). Potential physiological stresses on turfgrasses as a result of high temperature or drought stress will provide conditions conducive to increased weed pressures. McElroy and Bhowmik (2013) summarized weed management in turfgrass and concluded that weed pressures will exist in turfgrass, even under optimal growing conditions, but are more likely when turfgrasses are stressed.

Insect and disease responses to climate change are more difficult to assess (Walthall et al., 2012). We can make some general statements, for example, warmer temperatures will increase the number of life cycles in insects, increase the potential for overwintering of insects, and increased humidity will lead to more favorable environments for diseases. The exact relationship between an insect or disease and climate change will depend on the pest. In a recent review, Pautasso et al. (2012) summarized the potential impacts of climate change on plant diseases. Decreased plant health may occur because of increased pressure from pathogens. Additionally, faster incubation cycles and increased potential for abiotic stresses due to climate conditions in a specific ecoregion and more frequent chances of extreme weather events may also increase pest pressure (Chakraborty et al., 2000; Chakraborty and Newton, 2011; Pautasso et al., 2012).

Climate changes with increased temperatures, changing seasonality of precipitation, and more intense precipitation events with higher humidity will create stress conditions in turfgrasses, increasing the potential for disease outbreaks. Climate impacts on host plant physiology will be one of the major factors affecting the susceptibility of plants to diseases (Garrett et al., 2006). Hawkes et al. (2011) suggested that precipitation events were overlooked as a key climatic component that affected pathogens. Turfgrasses are subject to several diseases for which their prevalence is directly related to meteorological factors associated with climate change. For example, bacterial wilt (Xanthomonas translucens pv. Poae) occurs during periods with extended rainfall, and is increased if these rainfall periods are followed by warm weather and clear skies (Griffiths et al., 2007). Likewise, powdery mildew (Blumeria graminis) is fostered by cool- cloudy conditions with high humidity (Te Beest et al., 2008). The condition of the soil and soil temperatures affect the presence of summer patch (Magnaporthe poae) as found by Landschoot et al. (1989) in a survey of golf courses while Kackley et al. (1990a, 1990b, 1990c) identified the triggers for this turfgrass problem. Saturated soils can increase disease outbreaks triggered by soils with temperatures above 21°C with the first infection induced when soil temperatures exceed 18°C in the spring. Factors causing disease outbreaks are related to potential changes in meteorological conditions, and increasing variability in the environment could trigger disease outbreaks (Kerns and Tredway, 2013). Thus, enhanced scouting of diseases will be necessary when factors triggering diseases become more prevalent.

The optimal temperature range for the prevalence of insects varies by species. The often stated conclusion that the number of life cycles for an insect will increase with warming temperatures will follow the same relationship to temperature as turfgrass shown in Fig. 5. Conversely, there will be temperatures above the optimum where insect growth will decrease (Bale et al., 2002). The interaction between plant stress induced by unfavorable climate and insect pressures will become more critical with the increased chance of plant stress (Karuppaiah and Sujayanan, 2012). Entomologists have suggested more detailed studies are needed to quantify interactions between abiotic stresses and insect pressure (Guo et al., 2009). There have been increased efforts to link climate models and insect or disease models to project the changes in distribution of insects under a changing climate. For example, Gevrey and Worner (2006) showed that expanding ranges of the Mediterranean fruit fly (Ceratitis capitata) were related to changes in the average minimum temperature and potential evapotranspiration while changes in gypsy moth (Lymantria dispar) ranges were average minimum temperature and minimum daylength. After an analysis of historical records for several insects and pathogens, Bebb et al. (2013) concluded that the response of different species to a changing climate is variable; however, in general, there was a Northward progression across different species of 2.7 km ± 0.8 km yr⁻¹ with large variation among taxonomic groups. We can expect changes in the distribution and occurrence of different insects and diseases, translating in more intense scouting, and implementation of management practices to reduce the impact on the health of the turfgrass stands.

CONCLUSIONS

There are general changes in the climate; however, all impacts will be local because of microclimates in which turfgrasses are grown. Turfgrasses exist mainly in urban environments and the local conditions will deviate from the general trends in climate shown in Fig. 1 through 4. In the southern United States, continued increase in air and root temperatures will place warm-season grasses in an environment considerably above optimum temperatures. The same will be true for cool-season grasses in the transition zone, leading to replacement with warm-season species. One challenge for turfgrass management will be the maintenance of water in the soil profile in areas without irrigation; however, there is evidence that genotypic variation exists in the rate of water use and root exploration of a soil profile and understanding those differences will increase the potential for viable turfgrass stands. One of the major challenges for turfgrass management under climate change will be to quantify abiotic stresses and genotypic differences in the response to these stresses.

The social and ecosystem services provided by healthy and viable turfgrass requires that we begin to consider how to approach this problem and develop a quantitative understanding of climate impacts on both the abiotic and biotic stresses. The insights we gain from these studies will provide information valuable for all biological systems and improve our ability to sustain our food security and ecosystem services.
REFERENCES


