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# Turf: An integral part of an urban landscape

**Ranchana P, V Vasudevan, Santha A, Bhuvana D, Derina G and Ardra P Satheesan**

**Ranchana P**
Assistant Professor, Department of Agriculture, Karunya Institute of Technology and Sciences, Coimbatore, Tamil Nadu, India

**V Vasudevan**
Associate Professor, Department of Horticulture, Adhiyamaan College of Agriculture and Research, Athimughum, Tamil Nadu, India

**Santha A**
Student, Department of Agriculture, Karunya Institute of Technology and Sciences, Coimbatore, Tamil Nadu, India

**Bhuvana D**
Student, Department of Agriculture, Karunya Institute of Technology and Sciences, Coimbatore, Tamil Nadu, India

**Derina G**
Student, Department of Agriculture, Karunya Institute of Technology and Sciences, Coimbatore, Tamil Nadu, India

**Ardra P Satheesan**
Student, Department of Agriculture, Karunya Institute of Technology and Sciences, Coimbatore, Tamil Nadu, India

**Corresponding Author:**
**Ranchana P**
Assistant Professor, Department of Agriculture, Karunya Institute of Technology and Sciences, Coimbatore, Tamil Nadu, India

## Abstract

Turf grasses play an important role in urban greenery. A garden without a lawn will be incomplete. It possesses functional, recreational and ornamental values which enhance the quality of an urban living environment. A turf has numerous functional properties such as control of wind and water erosion of soil, collection of dust and dirt particles in the premises of residential buildings, factories, schools and business establishments, absorption of sound, noise, air pollution and heat Build Up. Many outdoor sports and recreational activities utilize turf including baseball, cricket, hockey, football, golf, lawn tennis and polo. In the present paper all the details and particulars are being amassed which would be useful for further studies. This can eventually be helpful in drawing the attention of the researchers and scientists to Work on it.

**Keywords:** turfgrass, classification, mowing, salinity, drought

## Introduction

The term 'turf' is derived from the Sanskrit term 'darbha', meaning 'tuft of grass' and the notion of lawn as a managed grass space dates to no later than the 16th century (Hoad, 1986) [43]. Turfgrass lawn coverage has of course been with civilization for a very long time. The term 'Turfgrass' refers only to the plant itself, whereas 'Turf' includes a portion of the medium in which the turfgrass are growing. Turfgrasses are defined as plants that form a dense ground cover that persists under regular mowing and traffic (Turgeon, 2002) [89]. Turfgrasses belong to one of the most evolutionarily advanced families of plants called Poaceae. The Poaceae is ubiquitous of the higher plant groups found on this earth subdivided into six subfamilies that include 25 tribes, 600 genera and 7500 species (Hoad, 1986) [43].

Among them turfgrass has a place with a standout amongst the most developmentally propelled groups of plants called Poaceae. All turfgrasses fall into three subfamilies; Festucoideae (cool-season turfgrasses), Panicoideae and Eragrostoideae which include the warm-season turf grasses.

For many centuries people have been willing to devote time and resources to enhance their quality-of-life and recreational opportunities through the use of turf grasses (Beard, 1989) [12]. Also, for many centuries turfgrasses have played a vital role in protecting our environment, long before it became issue of major national and international importance to modern societies. It is important through the world in enhancing and maintaining the function and beauty of contemporary landscapes (Githinji, 2009) [57].

It has overall significance in improving the capacity and magnificence of contemporary scenes. Employments of turf grasses can be recognized by their utilitarian, fancy and green space reason (Florida and Davison, 2001) [36]. It has worldwide importance in enhancing function and beauty of contemporary landscapes. Uses of turfgrasses can be distinguished by their functional, ornamental, recreational and green space purposes (Derrick, 2001) [29]. Fu *et al.* (2005) [37] reported that turfgrass is considered to be the most important ground cover in the world. It is chiefly utilized for yards, athletic fields, and fairways where legitimate choice and care of turfgrass relies on information of the ecological adjustment, social necessities and quality highlights of the grass species (Riaz *et al*., 2010) [77]. Turf grass industry also has a direct impact on the economy and indirect impact on the tourist economy of developed nations (Harivandi, 2009) [42]. Turfgrass industry also has a direct economic impact on the economy and indirect impact on the tourist economy of developed nations (Harivandi *et al.*, 2009) [42]. It is mainly used for lawns athletic fields and golf courses where proper selection and care of turf grass depends upon knowledge of the environmental adaptation cultural requirements and quality features of the grass species (Riaz *et al.*, 2010) [77].

All grasses are members of single family called Gramineae or Poaceae. However, only about 40 species are suited for turf use because of their tolerance and persistence to mowing traffic. Kabeer and Nair (2009) [50] reported that *Cynodon dactylon, Sporobolu shumilis, Zoysia matrella, Stenotaphrum dimidiatum* are good soil binders and have remarkable root systems.

## Evolution of turfgrass

The origin of the grasses has been dated 75 million years ago during late cretaceous period of Mesozoic era using the molecular dating method known as non-parametric rate smoothing (Bouchenak-Khelladi *et al.*, 2010) [16]. The specific characteristic of turfgrasses is the ability to withstand close mowing and still provide a functional, dense and healthy ground cover and that is what sets it apart from other plants and ground cover. Most of the turf-grasses we currently use was developed under the selection pressure of grazing animals. Before mechanical mowers were readily available, sheep grazing was used to maintain golf courses and other recreational sites.

Having a meristematic region closer to ground level and an initiated defense mechanism for some grasses such as trichomes, siliceous, dentations, alkaloids, phenolic compounds, and associations with endophytic fungi have all contributed to the co-evolution of grazing animals and grasses (Casler and Duncan, 2003) [23]. When grasses were subjected to grazing, only those plants with their growing points near the soil surface could survive. These were the first grasses we could call turf-grasses. They formed a continuous cover and could persist under regular mowing or grazing.

## Classification of turfgrass

Temperature and other environmental factors led to evolution of turf grasses with varied physiological and morphological differences. Based on the ranges of temperature and precipitation that the grasses adapt to, they are classified into warm season and cool season categories (Xu *et al.*, 2011) [95].

Two main physiological groups, warm-season ($C_4$ photosynthesis) and cool-season ($C_3$ photosynthesis) turfgrasses are made up of a diverse collection of individual species that have their own geographical ranges, growth habits, stress tolerances and input requirements. Warm-season turfgrasses are well-adapted to warmer regions in southern latitudes and cool-season turfgrasses are naturally adapted to regions with cooler temperatures in northern latitudes.

Cool and warm-season grasses differ in the time of season they are most actively growing. Cool-season grasses prefer the cool temperatures, while warm-season grasses prefer the hot temperatures of summer. This distinction between the types is a result of their differing photosynthetic pathways (Salisbury and Ross, 1992) [81]. At lower temperatures (10-25 °C), photosynthetic rates of warm-season grasses are equal to or lower than cool-season grasses. However, warm-season grasses, like other $C_4$ plants have higher photosynthetic rates than $C_3$ plants at higher temperature ($>25$ °C). Warm-season grasses photosynthetic processes are twice as efficient as cool-season grasses at temperature between 25 °C and 35 °C.

Warm season grasses are suited to regions with periodic drought and high temperature. Warm season grasses effectively pump carbon dioxide into the bundle sheaths which allows stomata to close when drought stress is occurring without limiting carbon dioxide needed for continued photosynthesis (Salisbury and Ross, 1992) [81]. Studies have also determined that warm-season grasses can be more competitive than introduced cool-season grasses as a result of higher growth rates even with low soil nitrogen levels (Brown, 1984) [17] and low soil moisture levels (Feldhake *et al.*, 1983; Kim and Beard, 1998) [34, 53]. They are well-adapted to warmer regions in southern latitudes and cool-season turfgrasses are naturally adapted to regions with cooler temperatures in northern latitudes.

There are quite a few varieties of grasses which are popular for turfing under warm conditions. Cow grass (*Axonopus compressus*), Bermuda grass (*Cynodon dactylon*), St. Augustine grass (*Stenotaphrum secundatum*), Manila grass (*Zoysia matrella*), Korean grass (*Zoysia japonica*) and Mexican grass (*Zoysia tenuifolia*) are a subset of warm-season species that are commonly used for turf (Beard, 1973; Turgeon, 1991) [11, 88]. Some mainstream grasses suitable for Indian conditions are given below in the table (Mathew *et al.*, 2021) [84].

**Table 1**

| **Common name** | **Botanical name** | **Region/climate** | **Special traits** | **Use and utility** |
|---|---|---|---|---|
| Kentucky blue grass | *Poa pratensis* (L.) | Temperate | Broad adaptation | Lawns, Sports, Golf |
| Perennial rye grass | *Lolium perenne* (L.) | Temperate | Rapid establishment, Broad adaptation | Lawns, Sports, Golf |
| Creeping bent grass | *Agrostis stolonifera* (L.) | Temperate | Low growth habit, aggressive spreading | Golf |
| Tall fescue grass | *Festuca arundinacea* (Schreb.) | Temperate | Broad adaptation, drought tolerance | Lawns, Sports, Golf |
| Bermuda grass | *Cynodon dactylon* (L.) | Tropical/Sub-tropical | Aggressive spreading, drought tolerance | Lawns, Sports, Golf, Low maintenance areas |
| Zoysia grass | *Zoysia japonica* (Steudel.) *Zoysia matrella* (L.) | Tropical/Sub-tropical | Dense sod, slow growth rate | Lawns, Sports, Golf, Low maintenance, areas |
| Centipede grass | *Eremochloa ophiuroides* (Munro) Hack. | Tropical / Sub-tropical | Low-fertility, acid-soil, and drought tolerances | Lawns, Low maintenance areas |
| Seashore paspalum | *Paspalum vaginatum* (SW.) | Tropical / Sub-tropical | Salt and drought tolerances | Lawns, Sports, Golf |
| St. Augustine grass | *Stenotaphrum secundatum* (Walt.) Kuntze | Tropical / Sub-tropical | Aggressive spreading, shade tolerance | Lawns, Low maintenance areas |
| Bahia grass | *Paspalum notatum* (Flugge) | Tropical / Sub-tropical | Drought and low- fertility tolerances | Low maintenance areas |

**Morphology and plant characteristics of turfgrass**

Warm season turfgrasses are best adapted to temperatures between 27 $^0$C and 35 $^0$C. Warm season species lose their chlorophyll as they go dormant and remain brown until spring (Christians, 2003) [25].

Chaffey (2000) [24] demonstrated the functional anatomy of ligules of 49 grass species from ten tribes. Most of the ligules consisted of three layers: the mesophyll and two epidermal cell layers. The mesophyll in those ligules contained chloroplasts. Grasses with ligules have higher fitness (Moreno *et al*., 1997; Korzun *et al.,* 1997). The main role of ligule is to protect the inner side of the leaf sheath from spores, water and dust, but in several species the ligule can also have a secretory function (Chaffey, 2000) [24].

Mintenko and Smith (1999) [69] studied 14 native grass species to turfgrass conditions with three mowing treatments. The study revealed that, all the grass species exhibit good color and quality except the Canada bluegrass under the combined stresses of heat and mowing. Among the grass species studied, Prairie Junegrass and Canada bluegrass had very early and rapid green-up. From this study, many grass species shown potential for turfgrass use, but promising species required breeding and a selection program for turf use before public use become a reality.

Seashore paspalum (*Paspalum vaginatum* O. Swartz) is a perennial $C_4$ turfgrass originating in South America in coastal regions (Duncan and Carrow, 2000; Turgeon, 2008) [31, 90]. Duncan and Carrow (2000) [31] suggested that Seashore paspalum (*Paspalum vaginatum* O. Swartz.) is known by a number of common names other than Seashore paspalum such as Silt grass, Saltwater couch and Sand knotgrass. It is adapted to saline soils and also exhibits superior drought resistance, wear tolerance, submersion tolerance, salt tolerance and recuperative potential. This species has stolons and rhizomes and its texture varies from coarse to very fine. It has pointed leaves and its blades are narrower than those of Bahia grass. The ligule is membranous with fine hairs protruding from its upper edge (Christians, 2007) [26].

St. Augustine grass provides a tight leaf canopy due to relatively prostrate leaf angle, which makes it highly resistant to weed infestation (Johns *et al.*, 1983) [49]. St. Augustine grass has round-tipped leaf blades 5 to 14 mm wide and they are arranged in a strictly distichous manner. It is a perennial, and it spreads by branching stolons, forming a coarse and spongy canopy.

*Zoysia matrella* is a salt tolerant turfgrass species with a higher density of larger salt glands secreting more sodium per unit leaf mass (Marcum and Murdoch, 1990) [65]. It forms extensive, velvety, green mats, spreading vigorously by stolons when established. In comparison with other warm-season turfgrasses Zoysia species have excellent cold hardiness and moderate drought and shade tolerance (Beard, 1973) [11]. These attributes have allowed for their expansion in transition zone.

Centipede grass (*Eremochloa ophiuroides*) is characterized by its dwarf phenotype with high resistance to drought and shade and is extensively planted as a turf grass around the world (Cai *et al*., 2004) [20]. Mintenko and Smith (2001) conducted an experiment on four native grasses *viz.*, Barkoel prairie junegrass, Bad River blue gramagrass, Golfstar Idaho bentgrass and alkaligrass in Randomized Completely Block design with four replicates. The result reported that, alkaligrass has tolerant to severe saline soil at both young and mature stages, while Bad river blue gramagrass, Golfstar Idaho bentgrass and Barkoel prairie junegrass has moderate salinity tolerance at mature stage. Alkaligrass shown tolerant to salinity level, future research should focus on need for cultivars and/or ecotypes with greater tolerance of mowing stress.

Adaptability of traditional turfgrass species to lower maintenance was studied (Doug Bred, 2002) [30]. The result had shown that, both fescue and Bermudagrass had thrived with less nitrogen and reduced irrigation, which ultimately results in less mowing frequency. The result exposed some traditional turfgrasses can prosper under reduced maintenance conditions.

Szabo *et al*. (2006) [86] studied the anatomy of ligule and morphology of five *Poa* species by light and scanning electron microscopy. All ligules studied are membranous, without veins and stomata-like structure and may have only a few mesophyll-like cells. The short leaf-like prickle hairs occurs rarely in *P. pratensis* and densely in *P. angustifolia*. The density of hairs on the abaxial surface is habitat dependent for all species studied. Ligule anatomy in the *P. pratensis* group is quite uniform, leading them to be grouped as closely related species, but the fine differences identified are useful for their identification.

Alessandro *et al.* (2007) [2] evaluated the adaptability of some warm season turfgrass species and cultivars to the latitudes of northern Italy. The results revealed that Bermuda grasses and in particular Tifway 419 has fastest establishment rate and *Zoysia matrella* cv. Zeon has recorded the best quality, highest shoot density and highest rhizome-stolon length per unit area.

Cowgrass (*Axonopus compressus* [Sw.] P. Beauv.) is a robust creeping perennial grass that forms dense mats popularly named as Tropical carpetgrass, broad-leaf carpetgrass and Blanket grass. It is mainly found in pastures roadsides and disturbed places or shaded areas in humid and sub-humid lowland tropics between 27$^o$ N and 27$^o$ S from sea level and up to 3000 m altitude (FAO, 2011; US Forest Service, 2011; Quattrocchi, 2006) [76]. It is often confused with *Axonopus affinis* but is more robust and stoloniferous and its spikelets are longer and hairy (FAO, 2011). It is also a useful ground cover and is used as a lawn grass in tropical and subtropical areas (FAO, 2011).

Namita and Janakiram (2012) [74] studied the turf grass species and varieties for various growth related qualitative and quantitative traits. The study says, all turfgrasses exhibited fine leaf texture except few have medium coarse and medium fine texture. Among the grasses evaluated, the *Agrostis palustris* L. exhibited maximum shoot density and minimum by *Cynodon dactylon* L. var. Panama. The maximum root density was observed in *Cynodon dactylon* L. var. Panama followed by *C. dactylon* L var. Panam.

Mutimura and Everson (2012) [72] conducted an experiment to determine the production of improved *Brachiaria* grass in comparison with indigenous *Brachiaria* under low rainfall and aluminium toxicity area. The overall results shows that *Brachiaria* hybrid cv. Mulato II had high adaptability to low rainfall and acidic soils stress and its production of green forage year-round when compare with other grasses and cultivars.

Pathick *et al*. (2013) studied the type, shape, structure and pattern of the ligule in 10 species of grasses, assessing their value in species identification, in absence of other vegetative or floral characters. The study revealed, that the morphological characters of the foliar ligule of the selected grass species, which are relatively vital to demarcate the different taxa in terms of phylogeny and taxonomy. In addition, this study is thriving to correlate between taxa and closely associated genera facilitating the identification of the species and its derivatives, in absence of other reproductive characters.

To compare the performance of savannah grass (SG) with Bermuda grass (BG) and *Zoysia* grass (ZG) by exposing to water and compactive stresses to assess the former's potential as an alternate turf grass species and also to compare temporal changes in reflectance and visual quality (VQ) ratings during stress was studied by Springer *et al.* (2014) [84]. Clipping yield (CY) was lower at the higher compaction effort for all turfgrasses, but across all stresses, drought (D) and waterlogging (WL) resulted in lower CY. SG had the highest clipping yield across all soils. Stress influenced turfgrass visual quality (VQ) with D stress, resulting in the lowest VQ rating among turfgrasses. Bermudagrass (BG) had the lowest VQ across all stress treatments, whilst, comparatively, Zoysia grass (ZG) had significantly higher VQ under high compaction (HC), low compaction (LC) and WL stress. Overall, SG showed a higher level of tolerance to applied stresses and warrants greater attention as a potential turfgrass under tropical conditions.

## Effect of mowing on turfgrass

Mowing is the costliest turf management operation, but also the most important, as good mowing practices are essential for achieving dense, quality turfgrass. Dense, quality turf requires mowing at proper height and frequency. Each tropical turfgrass species has an optimum mowing height range. Decreasing mowing height within this range will stimulate lateral branching, increasing turf density and quality. However, mowing below the minimum height for a given species will starve the turf, causing turf thinning (Marcum, 2010) [63].

Defoliation or mowing is a major turf management practice, along with fertilization, irrigation and pest control (Thorogood, 2000) [86]. The most fundamental practice for maintaining turf quality is mowing. It improves the appearance of the lawn and provides a uniform playing surface for certain sports (Christians, 2003) [25]. It removes nutrients from the turfgrasses by cutting the leaves (Woods, 2013).

The environmental conditions and growth habit of the vegetation should be known before selecting a maintenance practice for mowing. Many physiological changes of the vegetation will occur once it is defoliated by mowing. Plants can become more susceptible to environmental stresses once they have been defoliated or mowed. Excessive and continued removal of the photosynthetic material of plants causes decreased plant growth. Studies reported through several experiments that root development was negatively affected by defoliation and the subsequent reduction of the photosynthetic surface (Salaiz *et al*., 1995).

## Mowing height

In order to maintain an attractive and healthy turf, correct mowing height and mowing frequency must be followed. It is expected that mowing too high or too infrequently would increase weed colonization whereas just as mowing too low encourages weeds. Hence, an optimum intermediate mowing height and frequency would maintain a grass monoculture (Busey, 2003) [19].

Proper mowing height depends on the grass species, its growth habit, time of year, intended use of the area and the user's quality expectations. Busey (2003) [19] stated that lower mowing height is always associated with more weeds in turfgrass. Studies suggest that raising mowing heights by 0.8 to 1.5 mm has a significant effect on overall turf quality (Huang *et al*., 2004) [44].

Turfgrass areas should be mowed frequently enough so that more than 30% of the above ground tissue is never removed which is known as the 'one-third rule of mowing turfgrasses' (Christians, 2003) [25]. Consequently, the mowing frequency is determined by the desired turfgrass height and the rate of the turf (Matthew, 2001). Less frequent mowing often results in less shoot density and wider leaves (Beard, 2002) [13]. Mowing more frequently during periods of rapid growth can reduce the problems associated with clippings left on turfgrass, but most people are not willing or able to mow more frequently than about once per week.

Salaiz *et al*. (1995) [82] stated that if plants are mowed less frequently at higher heights, they have a better chance of not showing environmental stresses. Reduction in mowing frequency and increase in mowing height will help prevent decreased shoot density and reduced turf vigour (McCarty, 2001) [67].

Bermuda grass mowed at 1/8 inch had significantly more algae than mowed at 5/32 inch (Richards *et al*., 2007) [79]. This is likely due to the healthier and denser canopy found on plots with the higher mowing height.

## Growth of mowed turfgrasses

Proper mowing promotes rooting, tiller density and uniform growth. The best maintenance practice for Bermuda grass athletic fields is to mow frequently at a low height of cut that stimulates new growth and increases the density of the turfgrass stand. Mowing at heights lower than recommended encourages thin, weak turf that is less tolerant of athletic field foot traffic (Brosnan and Deputy, 2007) [18].

Under the regime of known mowing heights and one-third shoot tissue removal, Weeping grass (*Microlaena stipoides*) at mowing height of 25 mm and frequencies of 14 days interval over the growing season, provided not only improved tiller density, but also improved total yield and turf quality (Murdoch *et al*., 2007) [71].

Carter and Law (1948) [22] investigated the development of perennial grasses in the greenhouse with intense clippings at 15- and 30-days interval. Overall, they reported that the grasses decreased in plant top growth, root growth, tiller production and seed production. Root production decreased relatively greater than top production. They concluded that the production and viguor of vegetation varies inversely with clipping frequency.

Vivek (2012) [90] reported that for maintaining turfgrass under shade conditions, close mowing must be avoided, mowing height can be fixed at 50 - 70 mm from soil surface and fertilizer application must be moderate as excess nitrogen will lead to high disease incidence.

## Effect of growth retardants on the growth turf grass

Plant hormones are extremely important bioagents in the integration of developmental activities of plants. Apart from this, they also regulate the expression of intrinsic genetic potential of plants. Growth inhibition with plant growth regulators (PGRs) has become an important practice in turfgrass management (Watschke and Schmidt, 1992) [91]. PGRs are compounds which modify the hormonal status of plants and provide smoother putting surfaces by promoting lateral growth instead of undesirable top growth (Hedden and Hoad, 1994; Murphy *et al.*, 2001) [41].

PGRs modify turfgrass growth by inhibiting either cell division or cell elongation (Hedden and Hoad, 1994) [41]. A popular PGR in golf course management, paclobutrazol inhibits plant growth by blocking the enzyme *ent* – kaurene oxidase (Fletcher *et al.*, 2010) [35]. Triazole compounds which include paclobutrazol, unicanozole and triapenthenol inhibit the microsomal oxidation of kaurenol and kurenal (Izumi *et al.*, 1984) [46]. It is known that the triazole type of growth regulators may affect reactions other than ent- kaurene oxidation. Tatcyclacis is a norbornenodiazetine derivative which reduces gibberellin biosynthesis by blocking microsomal oxidation of kaurene and kaurenoic acid. It inhibits sterol biosynthesis by acting like triazole type of plant growth retardants. Prohexadione calcium and Inabenfide also have been found to have growth retardant activity by blocking gibberellin biosynthesis (Arteca, 1997) [8].

## Drought tolerance of turf grass

Worldwide climate change has led to increase in temperature and atmospheric $CO_2$ levels as well as deviations in rainfall patterns. Times of inadequate rainfall leading to drought are predicted to arise more frequently under such conditions and there is a decrease in availability of water to plants that cause the plants to suffer from entire metabolic activities (Bhargava *et al.*, 2013) [15]. Drought is one of the major abiotic stresses against the agricultural productivity and profitability around the world, since a large portion of yields of major crop plants developed to sustain the worldwide population are exceptionally delicate to drought. Dry season likewise prompts serious desertification, with a dynamic decrease of the vegetation spread combined with quick soil disintegration in dry and semi-arid-dry climatic locales. Dry season influences water potential and turgor in plants, bringing about the progressions of physiological and morphological qualities. Drought stress has a crucial effect on water relations, stomatal conductivity, chlorophyll content, photosynthesis, leaf area, metabolism, growth and yield of plants (Fallahi *et al.* 2015) [33].

Superabsorbent polymers, commonly known as hydrogels are networks of cross linked, that can imbibe 400 to 1500 times their dry weight in water. There are three classes of superabsorbent polymers which are classified as (1) Natural polymers are the polymers which are produced using naturally available organic materials like cellulose, chitin, starch and natural gums (Mehr *et al*, 2008) [3]. (2) Semi-synthetic polymers are manufactured from cellulose and combined with petrochemicals. (3) Synthetic polymers are made of polyacrylamides (PAM) and polyvinyl alcohols (Koupai *et al*. 2006) [54]. Darini *et al.* (2015) [28] experimented that the superabsorbent polymer on lawn under drought condition and revealed that superabsorbent polymer has a positive effect on shoot length, total chlorophyll, plant density and irrigation interval of lawn. Sheikhmoradi *et al.* (2012) [82] evaluated the effect of superabsorbent polymer on shoot growth of lawn and reported that there is a significant increase in the height of the shoot under treatment of 2-day irrigation interval with 25 g/m-2 superabsorbent. Darini *et al.* (2015) [28] conducted an experiment on lawn grass (*Cynodon dactylon* L.) by using superabsorbent polymer under water deficit conditions and reported that Superabsorbent polymer had a positive effect on root length and the longest root length was observed with application of 40 gm-2 SAP.

Jankowski *et al.* (2013) [48] experimented with four species *viz.*, perpetual ryegrass, red fescue, common meadow-grass, and common bent and found that, bedding with 5 cm depth of hydrogel placement, framed the most astounding root mass, and in the second year the most noteworthy shoot number was recorded in contrast with control. Agaba *et al.* (2011) [1] experimented on creeping bentgrass (*Agrostis stolonifera*) by amending hydrogel to sandy soil in order to improve the biomass and found that there is a significant increase in shoot and root biomass of *Agrostis stolonifera* by 2.2 and 4 times when compared to the control. A 0.4% of superabsorbent polymer in sandy soil increased the water use efficiency of creeping bentgrass (*Agrostis stolonifera*) when compared to control (Agaba *et al.*, 2011) [1]. Sheikhmoradi *et al.* (2012) [82] studied on turfgrass to determine the effect of superabsorbent polymer on qualitative characteristics of turfgrass and showed that application 30 to 35 g of superabsorbent polymer with an irrigation interval of two days preserved the quality of turfgrass while long irrigation intervals showed yellowing and wilting in control.

## Usage of saline and non-potable water in the turfgrass industry

Turfgrass sites are more frequently being considered as potential locations to use alternative water resources for irrigation. One reason is due to the vast amount of area that is used to grow turfgrass. Due to the large quantities of irrigation water necessary to maintain attractive turf with acceptable playability on golf courses and sports fields, wastewater may be an attractive alternative to irrigation with potable water (Mancino and Pepper, 1994) [59]. Potable water resources are becoming a scarce commodity due to population growth (Marcum, 1994) [10]. An average 18- hole golf course can use between 250,000 and 1,000,000 gallons of irrigation water per day to maintain the turf (Huck *et al.*, 2000) [45].

Water quality and water quantity are major problems worldwide, especially in water shortage areas (Glenn *et al.*, 1997) [38]. Water-related problems are enhanced in turfgrass sites using recycled water (Marcum, 1999) [61]. Managers for perennial turfgrass must deal with reduced growth, tissue dehydration, nutritional imbalances, and specific ion toxicities, slow recovery from injury, and poor long-term persistence that can be caused by salinity stress (Carrow and Duncan, 1998; Katerji *et al.*, 2000) [21, 52].

Switching to wastewater irrigation provides an opportunity for turfgrass managers to decrease operating budgets (Cuthbert and Hajnosz, 1999) [27]. In an arid region, potable water is expensive due to the scarcity of rain events and available water. According to Huck *et al.* (2000) [45], a large savings can be achieved by irrigating turf with waste waters that can cost 80% less than the fresh water equivalent. Transportation costs of recycled water irrigation are less in comparison to fresh water due to the fact that turfgrass sites are often present in urban areas where wastewater treatment plants are already located (Lazarova and Asano, 2005) [55]. Irrigation of turfgrass sites with wastewater sources also provides an opportunity to improve public perception of the turfgrass industry.

Wastewater, or reclaimed water, can be defined as treated or semi-treated water from a water treatment plant that has been remediated through physical and chemical means (Lazarova, 2005) [55] to a quality suitable for its intended use (Duncan *et al.,* 2009) [32]. Tertiary effluent water is likely to become the most prevalent water resource used as turfgrass irrigation. Additionally, there are many alternative water resources that can be allocated for irrigation in order to preserve potable water resources for human consumption. A few of these sources include ponds being fed by surface runoff from surrounding terrain, gray water, and groundwater from aquifers that are deemed unsuitable for human consumption (Duncan *et al*., 2009) [32].

One of the adverse effects of using irrigation water with increased levels of salts is decreased soil permeability. According to Carrow and Duncan (1998) [21], soil permeability is defined as “the ability of water, oxygen, and roots to move within the soil macro-pores for good turfgrass growth.” However, as Na ions, from irrigated salts, begin to dominate the CEC (Cation Exchange Capacity) sites of soil particles (through exchanges with other ions), the soil undergoes physical changes that decrease soil permeability. These changes can include the destruction of larger soil pore spaces, and reduction of pore continuity. Increased soil salinity can also drastically decrease water infiltration, percolation, and drainage. Other changes include an increase in water holding capacity of the soil, decreased soil $O_2$ due to the reduction in pore space and $O_2$ diffusion, and an increase in soil hardness (Naidu *et al*., 1995) [73].

In the turfgrass industry increased use of saline and non-potable water because of shortage of good quality water has increased the need for salinity tolerant turfgrass (Jalali *et al*., 2008) [47]. Salt affected turfgrass sites are becoming more common due to increased use of waste water or other irrigation sources containing salts, location of golf course on coastal sites that are susceptible to salt water intrusion, flooding, and salt spray and water conservation pressures that limit salt leaching or use of high-quality water in arid regions (Carrow and Duncan, 1998) [21].

The increased establishment of golf courses near coastlines and the impact of frequent saltwater exposure is another important reason to study salinity tolerance in turfgrasses (Carrow and Duncan, 1998) [21]. Turfgrasses growing near saltwater can be impacted by salt spray (Marcum, 1994) [10], and salt intrusion in groundwater (Carrow and Duncan, 1998) [21]. Salt spray can cause salt to accumulate on leaves and produce a foliar burn on the turfgrass verdure as well as increase the salinity of the soil (Bezona *et al.,* 1996) [14]. Due to increased human populations in coastal regions, increased use of fresh groundwater resources in these areas has caused the saltwater to move into the groundwater aquifers. Similar to salt spray damage, flooding of turf areas with saltwater will also result in foliar burn and increased soil salinity.

## Growth of turfgrass on salt affected sites

Soil salinity is considered as the major problem which adversely affects the yield and productivity of many agricultural crops across the world (Jungklang *et al*., 2003) [51]. The physical changes to the soil structure in response to increased sodium on the CEC are caused by a process called “dispersion”. Due to the sodium ion’s large size and charge, clay particles begin to repel and separate from adjacent soil particles resulting in destruction of soil structure. Dispersion is the primary physical process associated with increased sodium concentrations and ultimately the main cause of soil destruction and soil issues associated with wastewater irrigation of agriculture and turfgrass sites (Bauder and Brock, 2001) [10].

Decreased infiltration rates associated with soil dispersion can be caused by the dispersion of clay particles which then clog pore spaces and decrease water flow through the soil profile (Ayers and Westcot, 1976) [9]. The dispersive effects of sodium may also create soil crusting, where clay particles form a brick-like arrangement at the soil surface. Soil crusting further decreases soil permeability and can also prevent root penetration and emergence of new seedlings through the soil surface. Sodium chloride (NaCl) is the major salt contributing to the salinity in soils. Salt affected sites have high level of soluble salts, exchangeable Na, or both. According to the U.S. Salinity Laboratory, salt affected soils can be classified into three distinct categories: saline, sodic, and saline-sodic. (a) Saline a soil with high soluble salts (b) Sodic a soil with high exchangeable Na (c) Saline-sodic where both soluble salts and exchangeable sodium are high.

Saline soils, or white alkali soils, are characterized by electrical conductivity levels in excess of 4 dS m-1 and a sodium absorption ratio (SAR) <12 (Carrow and Duncan, 1998) [21]. Sodium absorption ratio is a measure of the amount of sodium ions in relation to calcium and magnesium ions. This measure is a way of representing the sodium status of a soil since the sodium ions are the most damaging to the soil and plants. The pH of saline soil is typically between 7 and 8.5, with sandy soils sometimes being slightly acidic.

The second type of salt affected soil is called sodic soils or black alkali soils. This condition is caused by large amounts of sodium on the CEC of the soil resulting in destruction of the soil structure. These soils are characterized by a SAR ≥ 12 and alkaline pH. Electrical conductivities of these soils are typically less than those of saline soils and are usually less than 4 dS m-1. Soil permeability issues due to salinity are usually associated with sodic soils because of the dispersive qualities of sodium ions in a soil’s CEC (Carrow and Duncan, 1998) [21].

The third and final type of salt affected soil is known as saline-sodic. This soil is characterized by an electrical conductivity over 4 dS m-1, similar to saline soils, as well as a SAR ≥12, similar to sodic soils. These soils are typically not affected by soil destruction and instead cause damage through osmotic stress on the plants due to the osmotic potential of the soils preventing water uptake by roots (Carrow and Duncan, 1998) [21].

Salinity induced inhibition of plant growth may occur due to excessive accumulation of Na, Cl or $SO_4$ concurrently with decreased accumulation of P, K, $NO_3$ and Ca (Zhu, 2011) [95]. Uptake of essential ions (both cations and anions) including $K^+$, $NH4^+$ and $NO3^-$ have been reported to be suppressed in various species by high levels of NaCl, especially in saline soil and irrigated water (Rubinigg *et al*., 2003) [79].

## Salt tolerant turf grass

Plants have two different mechanisms of salt tolerance including: 1) highly salt resistant cytoplasm, and 2) the ability to keep salt concentrations in the cytoplasm at low levels. Turfgrasses have evolved a number of different mechanisms in which to survive the stresses associated with salinity stress. These mechanisms include increased root growth, ion exclusion, osmotic adjustment, ion compartmentalization, formation of compatible solutes, and glandular ion secretion (Marcum, 2008a; Uddin and Juraimi, 2013) [82, 68].

Root growth will typically be stimulated under moderate salinity stress in salt tolerant turfgrasses. Since the roots are responsible for water uptake and water is transpired through the shoot tissue, an increase in the root/shoot ratio takes place in response to the osmotic stress imposed by increased salinity levels (Gorham *et al.,* 1985) [39]. It has been shown that salt tolerant grass species have increased root growth under low to moderate salinity stress. Species such as bermudagrass (*Cynodon spp*.), seashore paspalum (*Paspalum vaginatum* Sw., weeping alkaligrass (*Puccinellia distans* (Jacq.) Parl.) (Alshammary *et al.,* 2004) [7], and Manila (*Zoysia matrella* (L.) Merr.) have all shown significantly higher root growth under salinity stress when compared to control plants. However, in more salt sensitive species, a reduction in root growth has been shown to occur in relation to the control plants that were not exposed to salinity stress.

Excluding salt ions from shoot tissue and thereby preventing the toxic effects of these ions has been shown to be associated with the overall salinity tolerance of both $C_3$ (Qian *et al.,* 2001) [76] and $C_4$ (Marcum, 1999) [61] turfgrass species. The ability of turfgrasses to exclude salt ions, including $Na^+$ and $Cl^-$, from shoot tissue has been used to show cultivar differences within species with respect to salinity tolerance. For example, salt tolerant cultivars of bentgrass (*Agrostis spp.* L.) (Wu, 1981) [93], bermudagrass have been shown to have lower concentrations of salt ions in shoot tissue when compared to salt sensitive cultivars.

Much of the damage associated with salinity stress is as a result of physiological drought. In order to prevent damage caused by this, turfgrasses have evolved mechanisms of osmotic adjustment, or osmoregulation, where the osmolarity of the cell cytoplasm is increased to prevent water loss. Increased $Na^+$ ion concentrations within a plant cell will lead to improper cellular enzyme function. One way that salt tolerant turfgrasses decrease the concentration of $Na^+$ is to maintain a high $K^+/Na^+$ ratio by actively pumping $K^+$ ions into the cell and $Na^+$ ions out of the cell. Marcum and Murdoch (1990) [65] showed this mechanism of salinity tolerance to be important in the overall salinity tolerance among C4 turfgrass species.

Another method of overcoming salinity stress in turfgrasses is by accumulating damaging salt ions in vacuoles that account for 90-95% of the volume of a mature plant cell. By compartmentalizing the salt ions, damage to essential cell function is prevented. Formation of compatible solutes within the cell cytoplasm is a way that plant cells increase the osmolarity of the cell sap and prevent water loss from the cell under saline conditions. Examples of compatible solutes in plants include glycine betaine, proline, trigonelline, polyols, and cyclitols (Gorham, 1996). Historically, proline had been considered to be a compatible solute that conveyed salinity tolerance. However, recent research has shown that there is in fact a negative correlation with proline concentrations in turfgrasses (Marcum, 1999) [61] and instead is associated with plant injury (Marcum, 2008a) [82]. In a study comparing two different Kentucky bluegrass cultivars, Qian *et al.* (2001) [76] noted less proline in the more salt tolerant cultivar and correlated an increase proline concentration with a significant increase in leaf firing in response to salinity stress.

Glandular ion excretion is an additional survival mechanism in some salt-adapted plant species. Turfgrasses that have salt glands include grama species, buffalograss, bermudagrass, saltgrass species, dropseed species and zoysia grass (Marcum, 1999) [61]. Salt glands in turfgrasses consist of two cells: a basal cell that is attached to the leaf epidermis and a cap cell. These specialized excretion glands have been found on both the abaxial and adaxial surfaces of the leaves and are usually arranged in parallel rows that are flanking rows of stomata (Marcum, 2008a) [82]. Salt glands in turfgrasses are selective in which salt ions are excreted. It has been shown that $Na^+$ and $Cl^-$ ions are preferentially excreted compared to other ions such as $K^+$, $Ca_2^+$, and $Mg_2^+$. Research has been conducted that correlated overall salinity tolerance of eight turfgrass species with the rate at which salt glands are able to excrete salt ions (Marcum, 1999) [61]. In this study, highly salt tolerant seashore dropseed had five times higher $Cl^-$ excretion rates when compared to moderately salt tolerant bermudagrass and fifty times the excretion rate of salt sensitive buffalograss. Salt ion excretion was also highly correlated with intra specific salinity tolerance in 57 zoysiagrass cultivars and 35 bermudagrass cultivars (Marcum and Pessarakli, 2006) [66]. Salt gland density has also been shown to be highly correlated to salinity tolerance where salt sensitive *Zoysias japonica* Steud. had nearly four times fewer salt glands when compared to salt tolerant *Zoysia macrostachya* Franch & Sav (Marcum *et al.*, 1998 and Liu *et al*., 2023) [64, 23].

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