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ESTABLISHMENT OF TURFGRASS FROM SEED AND SOD IN SAND BASED SYSTEMS COMBINING SPRINKLER AND SUBSURFACE DRIP IRRIGATION SYSTEMS

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By

Roshaan Ahmed Khan Niazi, B.S. Agricultural Sciences

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Abstract

The establishment of turfgrass using subsurface drip irrigation (SDI) in sand based media has limited success. However, it is unknown if starting with overhead (sprinkler) irrigation and transitioning to SDI can enhance turfgrass establishment. Two experiments were conducted at Stephen F. Austin State University (SFASU) to investigate the establishment of "L-93" creeping bentgrass (*Agrostis stolonifera*) from seed and "TifEagle" ultra dwarf hybrid bermudagrass (*Cynodon dactylon x Cynodon transvaalensis*) from sod using sand based media. Each experiment consisted of two trials conducted in summer 2017 and spring 2018. Both creeping bentgrass trials and the spring ultra dwarf hybrid bermudagrass trial were conducted in a greenhouse, but the summer ultra dwarf hybrid bermudagrass was a field trial. All four trials consisted of 5 different treatments with four replicates. Treatments consisted of a control (overhead irrigation only) and four treatments that transitioned from overhead irrigation to SDI when the roots reached a depth of 0, 5, 10, and 15 cm.

The creeping bentgrass seed planted in the summer produced 80% turfgrass coverage and the best turfgrass quality for the overhead irrigation and 15 cm SDI treatments. The 5 and 10 cm SDI treatments had less than 50% turfgrass coverage and below average turfgrass quality ratings. The 0 cm SDI treatment that received no overhead irrigation failed to produce turfgrass. However, the creeping bentgrass percent turfgrass cover and turfgrass quality were similar for all treatments when planted in the

spring. Creeping bentgrass shoot growth in the summer was similar for all the SDI and overhead treatments. However, in the spring, the creeping bentgrass shoot growth was significantly better for the SDI treatments compared to the overhead treatment.

The ultra dwarf hybrid bermudagrass sodded in both the summer and spring had similar turfgrass percent green coverage, turfgrass quality and shoot growth for all treatments within each trial. However, the ultra dwarf hybrid bermudagrass sodded in the spring had higher turfgrass percent green coverage, turfgrass quality and shoot growth compared to summer sodding.

The results from this study suggest that creeping bentgrass seed and ultra dwarf hybrid bermudagrass sod can be successfully established using SDI in sand based media in the spring. In the summer, the creeping bentgrass seed requires the establishment of a root system and transition to SDI to successfully produce turfgrass. The ultra dwarf hybrid bermudagrass sod was successfully established without overhead irrigation.

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Introduction

Agriculture consumes more than two-thirds of the total freshwater of the planet. This causes a significant conflict in freshwater distribution between farming and other commercial sectors (Chai *et al*., 2016). The turfgrass industry consists of many groups, including seed and sod producers, developers, millions of homeowners, vegetation managers, cemetery managers, athletic field managers, lawn care operators, architects, landscape designers and contractors, roadside, parks and grounds superintendents, and golf course superintendents. Establishing turfgrasses by using sprinkler irrigation is the conventional method and most turfgrass establishment is achieved via this system. By using this method of irrigation, evaporation and run off are the main factors that cause significant loss of water.

There are two types of soils that are used in the establishment of turfgrasses; native soils and sand based soils (Beard, 1973). Sand based root zones are primarily chosen instead of native soil root zones for their ability to increase water infiltration and drainage through the root zone, improve gas exchange in the root zone, increase rooting depths, as well as offer resistance to compaction. These advantages of sand based root zones are specifically important for golf courses and sports fields that face adverse weather conditions (Beard, 1973). The primary problem in sand based systems with subsurface drip irrigation (SDI) is the limited capillary action of sand to wick water to the surface where the seed or sod is located to achieve germination or establishment (Weeaks *et al.*, 2007). Water limitations across the Southwest have placed increased demands for water conservation on golf courses and other recreational fields. While superintendents irrigate courses using over-the-top sprinklers, an alternate method could be the use of SDI (Weeaks *et al*., 2007). Establishment of turfgrass when using SDI in sand based systems has been challenging (Christians, 1998). Turfgrass is sown primarily from seed but also by sod and sprigs. Previous research in the establishment of seeded bentgrass in sand based systems using SDI has been limited (Leinauer and Makk, 2007, Leinauer *et al.*, 2010 and Weeaks *et al.*, 2007). The results of Suarez-Rey *et al.*, (2000) indicated that there was successful establishment of bermudagrass using SDI that was grown from stolons in a coarse-loamy over sandy soil. There has been no research conducted on the establishment of bermudagrass from sod by using sprinkler irrigation then transitioning to SDI. For this reason, more research is needed on the establishment of turgrasses by using water efficient systems (SDI) in order to conserve water.

To address this issue, this research consisted of two experiments, each experiment with two trials. This project evaluated the establishment of creeping bentgrass from seed and ultra dwarf hybrid bermudagrass from sod by combining initial overhead irrigation and then transition to SDI in sand based systems. For this experiment, one trial was in the field, and other three were performed in the greenhouse.

Objective

The objective of this research project is to evaluate the effectiveness of transitioning from overhead to SDI at established rooting depths of 0, 5, 10, and 15 cm in creeping bentgrass established from seed and ultra dwarf hybrid bermudagrass established from sod in sand based media.

Literature Review

Subsurface Drip Irrigation:

Subsurface drip irrigation (SDI) is defined in “Soil and Water Terminology” (ASAE, 1999) as “An application of water below the soil surface through emitters, with discharge rates generally in the same range as drip irrigation”. It means that water is applied directly to the crop root zone using buried polyethylene tubing, also known as a drip line, dripper line, or drip tape. Drip lines are available in varying diameters and thicknesses in order to maintain acceptable irrigation uniformity for different field lengths. Smaller diameter drip lines are used when short lateral lengths are required. As lateral length increases, a larger diameter drip line must be selected to maintain adequate irrigation uniformity (Jose *et al*., 2005). The first known reference to subsurface irrigation comes from China more than 2000 years ago (Bainbridge, 2001), where clay vessels were buried in the soil and filled with water. The water moved slowly across the soil wetting the plant roots. Subsurface drip irrigation was developed around 1959 in the United States (U.S.) as a drip irrigation variation (Vaziri and Gibson, 1972), especially in California and Hawaii. Since the early 1980s, in Coolidge, Arizona, SDI has been operating successfully on a 1,000 ha farm with melons, wheat and cotton (Colaizzi, 1999).

Capillary (upwards) movement of water is limited from the emitters in sandy soils. The limited capillary movement of water from emitters makes it difficult to provide enough moisture for the germination or establishment of plants in sand based soils (Grabow *et al*., 2008). A study conducted by Biswas *et al*. (2015) suggested that use of SDI with straw mulch significantly increased the yield of tomatoes compared to the use of SDI without mulch.

Subsurface drip irrigation eliminates surface runoff and evaporation. Storage of seasonal rainfall and infiltration rate are greater in dry soils, with a reduction in soil crusting (Lamm, 2002). Subsurface drip irrigation reduces the high evaporation losses by applying water directly to the root zone (Suarez-Rey *et al*., 2000). By increasing irrigation frequency in bentgrass, vertical shoot growth can be promoted, and as a result, water demand increases. Shallow root systems can be promoted by constantly wetting the soil, which causes less water to be utilized in the deeper soil profiles (Huang, 2006). Less frequently irrigated turfgrass uses less water than more frequently irrigated turfgrass (Gibeault *et al*., 1985; Kneebone *et al*., 1992). The frequency of water application depends on the type of soil and texture. Generally larger particle size soils, such as sandy soils, have less water holding capacity with good drainage compared to fine particle size soils such as silt and clay. Only 50% of irrigation water is available to grasses in sand based soils. Thus, sandy soils require frequent irrigation in order to meet the plant's demand, but can be irrigated with smaller volumes per irrigation. Clay loams and clay soils hold more water, but only 30 to 35% is available to meet plant demand (Huang, 2006).

Drip irrigation typically requires low pressure to operate, which results in lower energy costs (Sinobas and Rodríguez, 2012). In widely spaced crops, unnecessary water losses are reduced because a minor portion of the soil around the crop is wetted. There are fewer chances of weed germination and weed growth in drier soils. Without moisture on the surface, airborne weed seed germination is potentially reduced, reducing weed growth and providing better turf quality (Suarez-Rey *et al.*, 2000). Similarly, drier and less humid crop canopies reduce the chances for disease to occur. The installation of SDI can be sustained for a longer period if properly designed and maintained compared with sprinklers (Lamm, 2002).

Generally, the cost of installing SDI is much higher than sprinklers (Suarez-Rey *et al.*, 2000) and SDI requires a significant investment cost for its construction compared to some conventional irrigation methods (Lamm, 2002). Subsurface drip irrigation systems require constant maintenance and repairs at the right time. It is difficult to locate and repair leaks which are caused by rodents, especially if SDI is installed at deeper depths (Sinobas and Rodríguez, 2012). Overseeding operations and germination of turfgrass seed can be difficult when using SDI. Depending on the depth of installation and soil characteristics, germination rates are limited by using subsurface drip irrigation. To provide winter turf, overseeding is an important operation in southern states that is practiced annually on high value turfgrasses (Suarez-Rey *et al.*, 2000).

The yield of crops is also increased by providing favorable conditions for water uptake by the roots and water movement in the soil. Subsurface drip irrigation systems maintain constant soil moisture, allowing plants to utilize water and increase production (Segal *et al*., 2000). Irrigation frequency beyond one day causes a reduction in the yields of cucumber (*Cucumis sativus* L.) and melon (*Cucumis melo* L.) planted in sandy soils (Goldberg and Shmueli, 1970) while potatoes planted in a sandy soil showed increased water application efficiency, water use efficiency, and yield by increasing the number of irrigation pulses (Bakeer *et al.*, 2009). Variability in emitter flow is reduced with subsurface drip irrigation due to reduced hydraulic variation, root intrusion and deposition of soil particles compared to surface drip irrigation systems (Sinobas and Rodríguez, 2012).

Creeping Bentgrass and Ultra Dwarf Hybrid Bermudagrass in Golf Greens:

A number of parameters can be used to define playing quality on a golf course, but grass and soil are the most important factors. Parameters include rooting depth, bouncing of the golf ball on greens, the amount of dry spot on fairways and tee areas, and uniformity of playing quality. For playing quality on golf greens, golfers consider ball roll distance as the most important criteria that is influenced by the quality of turf (Jensen, 2012). The quality of turf is a function of its utility, appearance, and in the case of sports turf, its playability during the growing season. For golf greens, the ball should be held atop the turf with no obstruction. Golf greens should provide sufficient ball-holding capacity for properly directed approach shots and true putting to the hole from any position on the green (Turgeon, 2008). Therefore, golf course superintendents are keen to produce high values of ball roll distance (less resistance to ball roll) on golf greens (Jensen, 2012). For this reason, the turfgrass should tolerate low mowing heights on the golf greens for fast putting speed. Due to the golfer demands and expectations for fast putting speeds of the ball rolling, the production of creeping bentgrass has been pushed further south, irrespective of the warm humid climate (Foy, 2006). Hence, creeping bentgrass and ultra dwarf hybrid bermudagrass are being used in Texas. Texas is located in a transition zone. In the transition zone, creeping bentgrass can be used on golf greens. Because much of Texas is in the transition zone. It is possible to produce both high quality creeping bentgrass and ultra dwarf hybrid bermudagrass on golf greens. However, in south Texas, ultra dwarf hybrid bermudagrass is dominant. In Texas, there are freezing temperatures in winter. The freezing temperatures in Texas causes warm season grass to go dormant. In order to cope with this, along with fast ball rolling speeds, the use of creeping bentgrass on golf greens is preferred.

Creeping bentgrass is a cool season turfgrass and is adapted to cool climates due to its physiology and water requirements. Its growth period is the cool season. Its optimum temperature requirements are 15-24º C. Creeping bentgrass can be propagated by seed, sprigs and sods, but seed is the preferred method (NSW, 2018) There are many "new and improved" creeping bentgrass cultivars such as A-1, A-4, Crenshaw, G-1, and L-93. The cultivar 'L-93' creeping bentgrass is widely adapted with a fine texture and tolerance to low mowing heights (Barenbrug, *n.d.*). An improved cultivar of creeping bentgrass 'L-93' has improved disease, heat and drought resistance (Bonos *et al.*, 2001). The creeping bentgrass 'L-93' exhibits high quality dark green color on golf greens, tees and fairways. During the onset of spring, ‘L-93’ creeping bentgrass has the ability to green up rapidly (Barenbrug, *n.d.).* It outperformed other cultivars such as ‘Declaration’, ‘Penncross’, and ‘Putter’ due to its fast establishment and ability to endure cold winters and survive under drought conditions (McCann and Huang, 2008).

Creeping bentgrass is a C_3 grass in that, the initial molecule formed during photosynthesis is a 3 carbon compound called 3-phosphoglycerate (3-PGA) and differ’s physiologically from warm season grasses such as bermudagrass. Bermudagrass is a C_4 grass in which carbon dioxide (CO_2) is fixed to a molecule called 3-phosphoenolpyruvate (PEP) to produce a 4 carbon compound malate. In the photosynthetic pathway of C_4 grasses, CO_2 is transported to bundle-sheath cells from mesophyll cells via malate that have evolved biochemical CO_2 concentrating mechanisms that allows ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco) to function in an elevated CO_2 environment. The CO_2 assimilation rates are higher in C_4 species as compared to C_3 species. The leaf and water use efficiency is increased in C_4 grasses as compared to C_3 grasses due to both higher photosynthetic rates per unit leaf area and lower stomatal conductance (Ghannoum *et al.*, 2011). Creeping bentgrass is not adapted to the high temperatures typical of summers in southern climates due to its less adopatable tolerance to heat stress and diseases.

Common bermudagrass (*Cynodon dactylon*) is the most popular turfgrass being used in the southern warm and humid states of the U.S. Common bermudagrass can be propagated by seed, springs and sods. Bermudagrass is a warm season C_4 grass. It has a different physiology and has optimum temperatures of 26-32º C (Lucas *n.d*). Its temperature requirements are higher but water requirements are lower (NSW, 2018). For meeting golfer demands in the golf green, the common bermudagrass is not preferred due to its inability to be maintained at low mowing heights. In order to create fine textured golf greens comparable to creeping bentgrass. Ultra dwarf hybrid bermudagrass (*Cynodon dactylon x Cynodon transvaalensis*) was developed. It is sterile and can only be propagated vegetatively by sod and sprigs. In the 1990's, new ultra dwarf hybrid bermudagrass cultivars began replacing hybrid bermudagrasses on many golf courses. For golf greens specifically, ultra dwarf hybrid bermudgrass are used due to its tolerance to very low mowing heights and maintaining good quality of turf with excellent ball roll. 'TifEagle' ultra dwarf hybrid bermudagrass is used for special purposes such as golf greens, bowling greens, lawns, and tennis courts. 'TifEagle' ultra dwarf hybrid bermudagrass produces higher quality turfgrass surfaces as compared to 'TifDwarf" (TifEagle Bermudagrass, 2009). 'TifEagle' ultra dwarf hybrid bermudagrass can tolerate much lower mowing heights, as compared to other cultivars such as 'TifDwarf', and 'TifGreen' (Tucker *et al*., 2006). 'TifEagle' ultra dwarf hybrid bermudagrass has the ability to maintain its color throughout the summer (TifEagle Bermudagrass, 2009). 'TifEagle' ultra dwarf hybrid bermudagrass develops a deep root system with tolerance to vertical mowing. It produces more stolons as compared to other hybrid bermudagrasses (Hanna and Elsner, 1999).

Root Development in Bentgrass:

There is not a consistent relationship between water application and root development. Detrimental effects on root development are rare with recurrent irrigation on ventilated and well-drained soils (Kvalbein and Aamlid, 2014). Fu and Dernoeden (2008) found that drought stress imposed by deep and infrequent irrigation led to a 16% reduction in root diameter compared with light and frequently irrigated creeping bentgrass. Huang and Liu (2003) found that summer root decline in bentgrass occurred due to both the decreased production of new roots and the increased death rate of older roots, and that the decline could be associated with higher soil temperatures. The optimum air temperatures for shoot growth ranges from 15 to 24°C and soil temperatures for root growth for cool season grasses ranges from 10 to 18°C (Huang *et al.*, 1998). A study by Burgess and Huang (2014) found that elevated concentrations of carbon dioxide in the above ground environment may greatly increase the water use efficiency and promote root growth of creeping bentgrass.

Root Development in Bermudagrass:

A key aspect in the establishment of turfgrass sod is rapid rooting or ‘‘knitting’’ of the sod into the underlying soil. Factors that ensure rapid sod rooting include proper soil aeration, adequate moisture in the underlying soil, and transplanting techniques that minimize desiccation (Beard, 1973).

In warm season grasses such as bermudagrass, St. Augustine (*Stenotaphrum secundatum*), and bahiagrass (*Paspalum notatum*), there are hypotheses about the impact of irrigation on root extension in establishing sod. One hypothesis is that frequent irrigations with large amounts of water are needed to encourage rapid root growth, although there is the possibility that such intense irrigation could discourage deep rooting into the soil. A second hypothesis is that infrequent irrigations and/or deficit irrigations stimulate rapid root extension to reach layers deep in the soil that might contain stored water. Although deficit irrigation during establishment could be beneficial in terms of water conservation, it may also negatively impact shoot growth and sod establishment (Sinclair *et al.*, 2011).

Sand based Root Zones:

There are many types of layers found in golf greens, which negatively affect turfgrass health, most notably layering of different soil types, different sand topdressings, sand or soil layers from unwashed sod, sand topdressing overtop of native soil or "push-up" greens, and organic layers between sand layers from heavy and infrequent topdressing. In each case, the downward movement of water and air is impeded and the water may become perched. When water encounters a layer of a distinctly different soil texture it begins to move laterally or upwards, rather than downward. Once the entire area above the layer becomes saturated, water may then begin to move downward. This perching of water can last hours or days and result in poor root development between layers. In some cases, water between layers fills all the pore spaces leading to an anaerobic condition known as black-layer. Roots cannot survive in the absence of oxygen in pore spaces, and gases released in the black-layer are lethal to roots (Dernoeden, 2013).

Sand (medium and coarse) as a root zone material has several characteristics that make it an optimal choice for growing turfgrass on golf courses and athletic fields. The sand particle size is larger than that of clay or silt, and sand particles tend to have a more rounded shape (Hillel, 2004). These characteristics allow for increased infiltration, increased drainage, increased gas exchange, and more resistance to compaction, which provide an environment more conducive to root growth (Beard, 1973). The United States Golf Association (USGA) has a set of guidelines for soil texture, sand particle size, and percentages not more than 10% very coarse sand particles (1.0 to 2.0 mm), not more than 20% fine sand (0.15 to 0.25 mm), not more than 5% very fine sand (0.05 to 0.15 mm), coarse sand (0.5 to 1.0 mm) and medium sand (0.25 to 0.50 mm) not more than 57%, not more than 5% silt (0.002 to 0.05 mm) or not more than 3% clay (less than 0.002 mm), combined that can be used during construction of the root zone for golf greens, although the sand particle size can be 100% uniform (USGA, 1993). For approved USGA putting green construction, there are seven requirements that include (1) subgrade, (2) drainage, (3) gravel and intermediate, (4) root zone mixture, (5) top mix covering, placement, smoothing, and firming, (6) seed bed preparation, and (7) fertilization. The selection of a root zone mix is of major importance in the construction of a putting green. It is recommended by the USGA (2004) to add one of several organic materials such as peat moss, finely ground bark, sawdust, rice hulls, or other products to the sand. The purpose of adding organic material with sand is to increase the water holding capacity of the media.

Irrigation Frequency:

There is an ongoing debate within the turfgrass industry whether light and frequent, or deep and infrequent irrigation is best. Frequent irrigation of putting greens to prevent water stress has been shown to produce shallow-rooted turfgrass with reduced tolerance to environmental stress. Different irrigation timings and volumes affect turfgrass disease, growth, root production, and health. Jordan *et al*. (2003) found that irrigating on a 4 day frequency, as compared to every day or every other day frequency, significantly increased shoot density and root length density of creeping bentgrass grown on a sand based root zone. Fu and Dernoeden's (2008) findings showed that creeping bentgrass, grown in a sand based root zone and irrigated at visual signs of wilt stress, produced an extensive root system compared to light and regularly irrigated creeping bentgrass. Jordan *et al*. (2003) also recognized that overall turfgrass quality was identical when irrigating at these frequencies in Texas. Even with thicker density turfgrass, visual quality ratings showed no differences due to varying irrigation frequencies. Irrigating every day was found to contribute to high soil temperatures and low soil aeration. Irrigating less frequently could result in better root uptake of water and improved drainage of surplus irrigation water, which would have improved soil aeration and encourage root growth (Jordan *et al*., 2003). Qian *et al*. (1997) concluded that turfgrasses irrigated less frequently produced larger root systems, ultimately resulting in higher turfgrass quality. Frequent or excessive irrigation not only increases costs associated with water consumption, but can reduce environmental stress tolerance and predispose turfgrass to injury from mechanical stresses, cyanobacteria, moss, and diseases (Beard, 1973; Dernoeden, 2002; Turgeon, 2008). High soil moisture levels caused by prolonged periods of rainfall or irrigation can be responsible for runoff and nutrient losses even on established dense turfgrass (Linde *et al*., 1995). Sass and Horgan (2006) found that daily irrigation resulted in a large proportion of water ending up in the upper 5 cm of a sandy soil. Water in this range is more subject to high rates of evaporation and thus is less available to the turfgrass. They also found that irrigating with low volumes of water limits the depth of infiltration and that a large proportion of that water never makes it past the thatch layer. Huang and Liu (2003) found that during the summer months, creeping bentgrass roots remained mainly in the upper 10 cm of the soil profile. If the irrigation percolates past the top 10 cm of the soil profile, it can cause a water loss because it will be unavailable to the plant. In sand based soils, infrequent irrigation does not decrease the creeping bentgrass quality due to lower turgor pressure (Jordan *et al*., 2003)

Beard (1973) recommended that in order to maintain the moisture level on a daily basis of newly laid sod, less frequent water is required for thick cut sod (1-2 cm) than thin cut sod (<1 cm). Zoysiagrass established from sod can be better prepared for upcoming drought with deep infrequent irrigation than with light frequent irrigation (Qian and Fry, 1996).

Water Uptake and Transport:

Through the process of evaporation, water moves from soils to the atmosphere; however, on turfgrass surfaces, water loss occurs mainly through transpiration. Transpiration is the process that generates tension within the plant that pulls the water that is present in the soil out of the soil pores. The process that combines transpiration from plants and evaporation from the soil is called evapotranspiration (ET). Plant roots may be unable to absorb water because the micropores of diameter <0.005 mm bind the water tightly. Soils with a high ratio of clay particles or decomposed organic matter contain a considerable amount of water which is present below the 'wilting co-efficient'. This small quantity of water is termed unavailable water (Kvalbein and Aamlid, 2014).

Water moves internally through xylem that is continuous from the root hair zone of the roots, through the stem, and to the mesophyll cells of leaves. Movement of water occurs primarily due to transpiration. A hydrostatic gradient develops between the leave's evaporation zone and the water absorption of the roots with the flow of water along gradients of decreasing water potential. Water potential of the mesophyll cells decreases due to the evaporation of water from the surface of the leaf. This causes diffusion of water from xylem towards mesophyll cells and create a tensile strain throughout the length of the xylem due to the hydrogen bonding of water molecules. This tension pulls the water upward through the xylem tissue and causes water to diffuse into the lower regions of the xylem from the adjacent root cells. Because of lower potential of the cells adjacent to the xylem in the root, water enters root hairs and diffuses passively through the cells of the cortex into the central vascular zone of the root (Beard, 1973).

Water Movement in the Soil:

Water moves downward and does not remain stationary in soil due to gravitational flow. It moves from a higher concentration (ψ) to a lower concentration (ψ). Water also moves in the soil through capillary flow. This capillary flow occurs through the micro pores (Sheard, 1992). Capillary movement of water in soil is of great importance in terms of supplying water to the roots of turfgrass. Due to the absorption of water by the turfgrass roots, capillary flow allows water to be replenished at the surface of a root. Capillary flow depends on the size of pores in the soil, and sand has large micro pores (Sheard, 1992). In sand based soils, this upward movement of water by capillary rise is fast but covers only a short distance. In coarse sand, groundwater can be moved upward through capillary rise 20 to 50 cm (Brouwer *et.al.*, 1985)

EXPERIMENTS

Experiment 1: Trials 1A and 1B: Establishment of Creeping bentgrass (*Agrostis stolonifera*) from seed in sand based systems combining sprinkler and subsurface drip irrigation systems.

Introduction

Sprinkler irrigation is the most common and conventional way of establishing turfgrasses and irrigating large stands of turfgrass. Evaporation and run off are the primary factors causing significant loss of water when using sprinkler irrigation systems. Using sprinklers has many disadvantages as worn nozzles on sprinkler heads and wind can affect uniformity of water application (Gross, 2004). Inaccurate spacing between sprinklers and imprecise pressure of the worn sprinkler nozzles reduces the uniformity of water application. Subsurface drip irrigation (SDI) is defined as "An application of water below the soil surface through emitters, with discharge rates generally in the same range as drip irrigation" (ASAE, 1999). Using SDI may help to eliminate many of the inherent problems in golf course irrigation. Subsurface drip irrigation improves uniformity of water application, eliminates evaporation and wind drift (Beccard, 2005).

Establishment of turfgrass when using SDI in sand based systems has been challenging (Christians, 1998). Sand based media have limited capillary action in order to provide enough moisture to the soil surface for the establishment of creeping bentgrass when using SDI, and research in the successful establishment of seeded bentgrass in sand based systems using SDI is limited (Leinauer and Makk, 2007, Leinauer *et al.*, 2010 and Weeaks *et al.*, 2007). Previous research showed a lack of full turfgrass cover in creeping bentgrass establishment from seed in sand based media (Weeaks, 2009). By using SDI, it is difficult to rewet the surface from the bottom when it dries. If there is lack of continual wetting by SDI at the surface, the germination of the bentgrass fails (Weeaks *et al.*, 2007).

There are generally two types of soils that are used in the establishment of turf grasses: native soils and sand based soils (Beard, 1973). Golf greens are commonly built using the USGA method of construction (USGA, 2004). This method uses coarse (1.0 to 2.0 mm) and medium sand (0.25 to 0.50 mm) as the primary constituent. The USGA allows a wide variety of amendments that can be added to a maximum of 20% by volume to the final root zone mixture in order to increase water holding capacity. Included in this list are organic amendments such as peat moss, rice hulls, finely ground bark, sawdust, and other properly treated organic wastes (USGA, 2004). The most commonly used organic amendment is peat moss (USGA, 2004).

Creeping bentgrass is a fine textured turf with superior shoot density, uniformity, and turfgrass quality when closely mowed. The extremely high density of a creeping bentgrass turf provides an excellent playing surface on greens.

The objective of this research is to evaluate the effectiveness of transitioning from overhead to SDI at established rooting depths of 0, 5, 10, and 15 cm in seeded creeping bentgrass in sand based media.

Materials and Methods

Trials (1A and 1B) were conducted in a glass greenhouse located on the Stephen F. Austin State University (SFASU) campus in Nacogdoches, Texas. Both trials were conducted for eight weeks to evaluate establishment of creeping bentgrass in sand based systems when transitioning from overhead irrigation to SDI. Trial 1A was initiated on 23 September 2017 and Trial 1B on 5 March, 2018. Both trials consisted of five different treatments with four replicates. Treatments consisted of a control (overhead irrigated only) and four treatments that transitioned from overhead irrigation to SDI when the roots reached a depth of 0, 5, 10, and 15 cm. There were two sources of sand used in the trials: source 1 sand (trial 1A) was obtained from David Kolb Excavation, Nacogdoches, TX and source 2 sand (trial 1B) was obtained from Crown Colony Country Club, Lufkin, TX. Soil samples were collected and analyzed for soil texture and nutrient concentrations at the SFASU Soil, Plant and Water Analysis Laboratory (Tables 1.1 and 1.2). Sand in both trials were amended with 10% peat moss. The SDI system used for these two trials consisted of Rain Bird XFD-100 Series drip tubing with a flow rate of 1 L hr^{-1} (Rain Bird Corporation, CA). There were 21 buckets (19 liter) used in each trial, each considered a lysimeter. One lysimeter was used to determine rooting depth while the other 20 lysimeters were used for the specific treatments. Each lysimeter was 38 cm tall and 30 cm (28 cm inside rim) in diameter with an area of 0.061 m^2, with a single 0.6 cm diameter hole drilled in the side near the bottom of the container for drainage. Holes

(17mm diameter) were drilled into each side of the lysimeter at a depth of 15 cm from the top to facilitate the drip line with a single emitter. The drip tubing emitter orifice was positioned directly in the center of the lysimeter. The ends of the tubing of each lysimeter were connected together by using blank tubing to carry water to the four lysimeters of each treatment. The opposite side of the tubing of a lysimeter was capped by folding over the tubing to avoid any leakage of water.

Table 1.1. Soil texture analysis of trial 1A and trial 1B sand

	Trial 1A	Trial 1B
	%	%
Clay (< 2µm)	10	07
Silt (2 - 50µm)	03	03
Sand (50 - 2000µm)	87	90

Table 1.2. Soil chemical analysis of trial 1A and trial 1B sand.

	Trial 1A	Trial 1B
pH	7.82	7.89
Nutrients	(mg L^{-1})	(mg L^{-1})
Na	46.313	54.968
P	3.471	1.673
K	12.611	17.346
Ca	53.593	175.129
Mg	10.932	19.253
S	13.042	81.301
Fe	4.039	8.736
Mn	0.101	0.653
Zn	0.106	0.301
Cu	0.041	0.045

A 2.5 cm layer of pea gravel was placed in the bottom of each lysimeter. Media was prepared in a drum-type mixer by mixing 90% sand with 10% peat moss volume to volume to ensure a homogenous mixture. Once well blended, media was placed into each lysimeter, and drip tubing was inserted into the sidewall of each lysimeter. Before the sowing of seed, all the lysimeters were well watered with overhead irrigation to settle the sand media.

Creeping bentgrass (*Agrostis stolonifera)* “L-93” certified seed obtained from Simplot (Liberty Lake, WA) was seeded at the rate of 6.04 g m^{-2} pure live seed. Creeping bentgrass seed (0.36 g per lysimeter pure live seed) was mixed with sand before it was uniformly spread on the surface of each lysimeter.

Irrigation cycles were varied based on plant development. After sowing, the lysimeters for the overhead, 5, 10, and 15 cm SDI treatments were irrigated overhead with a hand held spray nozzle to simulate sprinkler irrigation. The control treatment in both trials was the application of overhead irrigation. The SDI was given only to the 0 cm SDI treatment three times a day during the 1^{st} week while overhead irrigation was provided three times a day in both trials to all other lysimeters at 10 am, 2 pm and 6 pm. The irrigation was applied two times (10 am and 6 pm) a day after week 1. In week 3 after sowing, all the lysimeters were irrigated once a day (10 am) until the end of the experiment. The 5, 10, and 15 cm SDI treatments were irrigated with overhead irrigation until the roots reached a depth of 5, 10, 15 cm, respectively, then switched to SDI for the remainder of the trial. Roots reached a depth of 5, 10, and 15 cm for the 5, 10, and 15 cm SDI treatments in weeks 2, 4, and 5, respectively. The root depth was determined weekly from the sample lysimeter in both trials by collecting core samples with a soil probe.

Trial 1A did not receive any fertilization. Fertilizer was applied in trial 1B via fertigation beginning 3 weeks after seeding. Each lysimeter received 473ml of a 250 mg N L^{-1} water soluble fertilizer solution weekly. The fertilizer was Peter's Professional 20N-4P-17K fertilizer including magnesium-0.15%, boron-0.0125%, copper-0.0125%, iron-0.05%, manganese-0.025%, molybdenum-0.005%, and zinc-0.025% (ICL, Dublin, OH). Data was collected weekly for percent turfgrass cover, turfgrass quality, and turfgrass growth (shoot length). Volumetric soil moisture content of each lysimeter was collected weekly using a TDR 100 Soil Moisture Meter (Spectrum Technologies Inc., Plainfield, IL) with a sensor length of 12 cm by inserting it into the media approximately 5 to 10 cm away from the drip emitter. Turfgrass growth (shoot growth) data was collected by measuring turfgrass height from the surface of the lysimeter rim. After weekly measurements of shoot growth, the shoots were removed to the lysimeter rim with a scissor. The rating system for visual observations of percent turfgrass cover was that used by the National Turfgrass Evaluation Program (NTEP): 1= no coverage, 5= 50% coverage and 9= 100% coverage. The visual observations of turf quality was based on a scale of 1 as poorest to 9 as best (NTEP, 2004). There was no data collected during the week of seeding because there was no creeping bentgrass present to evaluate.

The experimental design was a randomized complete block design (RCBD) with 4 replications. The data was analyzed using SAS 9.2 (Cary, NC) via One-Way ANOVA. GLM model was used for the data analysis and Tukey's studentized range test (HSD) was used for means separation where differences occurred at the 5% significance level.

Results

Trial 1A: Visual turfgrass percent cover ratings.

The overhead, 5, 10, and 15 cm SDI treatments had similar percent turfgrass cover ratings for weeks 1 to 4 (Table 1.3). The 0 cm SDI treatment failed to produce any turfgrass throughout the trial. In week 5, the overhead, 10, and 15 cm SDI treatments had significantly greater percent turfgrass cover than the 5 cm SDI treatment. In week 6, the overhead and 15 cm SDI treatments had significantly more turfgrass coverage than the other treatments, and the 10 cm SDI treatment had significantly more turfgrass coverage than the 5 cm SDI treatment. In week 7, there was significantly more percent turfgrass cover for the overhead and 15 cm SDI treatments compared to the other treatments. The 5 and 10 cm SDI treatments were not significantly different from each other. There was no decline for the overhead and 15 cm SDI treatments over time, but some decline was noted for the 5 and 10 cm SDI treatments.

Table 1.3. Percent cover ratings transitioning from overhead to subsurface drip irrigation at established rooting depths of 0, 5, 10, and 15 cm of creeping bentgrass for trial 1A. Means within columns with the same alphabetic letters are not significantly different at the 0.05 level.

Irrigation Treatments	23 Sept Seeded	30 Sept Wk1	07 Oct Wk2	14 Oct Wk3	21 Oct Wk4	28 Oct Wk5	04 Nov Wk6	11 Nov Wk7
Overhead	N/A	7.3a	6.5a	5.5a	6.5a	7.3a	7.0a	7.0a
0 cm SDI	N/A	0.0b	0.0b	0.0b	0.0b	0.0c	0.0d	0.0c
5 cm SDI	N/A	6.8a	6.0a	5.5a	5.3a	5.0b	5.0c	3.8b
10 cm SDI	N/A	6.5a	6.0a	5.5a	5.8a	6.5a	6.0b	4.3b
15 cm SDI	N/A	7.5a	6.3a	6.3a	6.3a	7.8a	7.0a	6.8a
P- value	N/A	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001

Trial 1A: Visual turfgrass quality ratings.

In weeks 1 and 2 (Table 1.4), there was no significant difference in turfgrass quality between the overhead, 5, 10, and 15 cm SDI treatments. In weeks 3 and 4, the overhead, 10, and 15 cm SDI treatments had significantly better turfgrass quality compared to the 5 cm SDI treatment. In week 5, the overhead and 15 cm SDI treatments did not differ significantly, but were significantly better than the 0 and 5 cm SDI treatment, with the overhead significantly better than the 10 cm SDI treatments. The 10 and 15 cm SDI treatments had similar ratings. In week 6, the overhead and the 15 cm SDI treatments had significantly better turfgrass quality compared to the other treatments, with the 10 cm SDI treatment having significantly better turfgrass quality than the 5 cm SDI treatment. In week 7, the overhead and the 15 cm SDI treatments had the best turfgrass quality.

Table 1.4. Turfgrass quality ratings transitioning from overhead to subsurface drip irrigation at established rooting depths of 0, 5, 10, and 15 cm of creeping bentgrass for trial 1A.
Means within columns with the same alphabetic letters are not significantly different at the 0.05 level.

Irrigation Treatments	23 Sept Seeded	30 Sept Wk1	07 Oct Wk2	14 Oct Wk3	21 Oct Wk4	28 Oct Wk5	04 Nov Wk6	11 Nov Wk7
Overhead	N/A	7.0a	8.0a	9.0a	7.8a	9.0a	8.8a	8.0a
0 cm SDI	N/A	0.0b	0.0b	0.0c	0.0c	0.0d	0.0d	0.0c
5 cm SDI	N/A	7.3a	6.8a	8.0b	5.5b	5.5c	4.8c	3.5b
10 cm SDI	N/A	6.3a	8.0a	9.0a	6.8a	7.8b	6.5b	4.0b
15 cm SDI	N/A	7.5a	7.8a	9.0a	7.5a	8.8ab	8.8a	6.8a
P- value	N/A	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001

Trial 1A: Turfgrass height measurements.

The overhead, 5, 10, and 15 cm SDI treatments had similar turfgrass height in weeks 1 to 4. In week 5, the 10 cm SDI treatment had significantly greater height compared to the overhead, and 15 cm SDI treatments. In week 6, the 5 and 10 cm SDI treatments had significantly greater height than the overhead treatment but not the 15 cm SDI treatment (Table 1.5).

Table 1.5. Turfgrass height measurements (cm) transitioning from overhead to subsurface drip irrigation at established rooting depths of 0, 5, 10, and 15 cm of creeping bentgrass for trial 1A.
Means within columns with the same alphabetic letters are not significantly different at the 0.05 level.

Irrigation Treatments	23 Sept Seeded	30 Sept Wk1	07 Oct Wk2	14 Oct Wk3	21 Oct Wk4	28 Oct Wk5	04 Nov Wk6	11 Nov Wk7
Overhead	N/A	1.4a	0.7ab	1.1a	0.6a	0.7c	1.1b	2.3a
0 cm SDI	N/A	0.0b	0.0b	0.0b	0.0b	0.0d	0.0c	0.0b
5 cm SDI	N/A	1.2a	0.9a	0.9a	0.8a	1.0ab	2.0a	2.0a
10 cm SDI	N/A	1.1a	0.8ab	0.9a	0.5a	1.3a	2.2a	3.6a
15 cm SDI	N/A	1.2a	1.0a	1.0a	0.5a	0.8bc	1.4ab	2.6a
P- value	N/A	0.0007	0.0347	<.0001	<.0001	<.0001	0.0002	0.0029

Trial 1A: Soil moisture measurements.

At seeding, the overhead, 0, 5, 10, and 15 cm SDI treatments had similar soil moisture percentages (Table 1.6). By week 1, all but the 0 cm SDI treatment had similar soil moisture percentages. For weeks 2 and 3, the overhead, 10, and 15 cm SDI treatments had significantly higher soil moisture percentages than the 5 cm SDI treatment. For weeks 4 and 5, the overhead treatment had significantly higher soil moisture percentages than the 5 cm SDI treatment, but the 10 and 15 cm SDI treatments were not significant higher than the 5 cm SDI treatment. For weeks 6 and 7, the overhead treatment had significantly higher soil moisture percentage than the 5 cm SDI treatment and the 5, 10, and 15 cm SDI treatments had similar percentages (Table 1.6).

Table 1.6. Soil moisture measurements (%) transitioning from overhead to subsurface drip irrigation at established rooting depths of 0, 5, 10, and 15 cm of creeping bentgrass for trial 1A.
Means within columns with same alphabetic letters are not significantly different at the 0.05 level.

Irrigation Treatments	23 Sept Seeded	30 Sept Wk1	07 Oct Wk2	14 Oct Wk3	21 Oct Wk4	28 Oct Wk5	04 Nov Wk6	11 Nov Wk7
Overhead	5.5	2.9a	3.7a	2.8ab	5.1a	3.8a	6.7a	6.1a
0 cm SDI	4.4	0.0b	0.0c	0.3c	0.0c	0.0c	0.0c	0.0c
5 cm SDI	6.1	2.8a	1.9b	1.8bc	1.9bc	1.5bc	3.3b	2.8b
10 cm SDI	5.6	2.8a	3.8a	2.2ab	4.4ab	2.2ab	5.7ab	3.9ab
15 cm SDI	6.5	2.9a	3.7a	3.4a	4.4ab	3.4ab	5.8ab	4.7ab
P- value	0.1655	0.0009	<.0001	0.0009	0.0017	0.0019	0.0009	0.0001

Trial 1B: Visual turfgrass percent cover ratings.

There was no significant difference between the overhead, 0, 5, 10, and 15 SDI treatments throughout the trial, with all the treatments showing 100% turfgrass cover at the end of a trial (Table 1.7).

Table 1.7. Turfgrass percent cover ratings transitioning from overhead to subsurface drip irrigation at established rooting depths of 0, 5, 10, and 15 cm of creeping bentgrass for trial 1B.

Irrigation Treatments	5 Mar Seeded	12 Mar Wk1	19 Mar Wk2	26 Mar Wk3	2 Apr Wk4	9 Apr Wk5	16 Apr Wk6	23 Apr Wk7
Overhead	N/A	7.8	6.5	6.5	6.3	7.5	9.0	9.0
0 cm SDI	N/A	7.8	7.5	6.3	6.5	8.5	9.0	9.0
5 cm SDI	N/A	7.8	7.3	7.5	7.5	8.5	9.0	9.0
10 cm SDI	N/A	7.3	6.5	6.3	6.3	7.8	9.0	9.0
15 cm SDI	N/A	7.5	6.8	5.5	6.8	8.5	9.0	9.0
P- value	N/A	0.7628	0.2940	0.3093	0.4151	0.1318	N/S	N/S

Trial 1B: Visual turfgrass quality ratings.

There was no significant difference in turfgrass quality between the overhead, 0, 5, 10, and 15 cm SDI treatments for weeks 1 to 4, 6, and 7. In week 5, all SDI treatments had significantly better turfgrass quality than the overhead treatment (Table 1.8).

Table 1.8. Turfgrass quality ratings transitioning from overhead to subsurface drip irrigation at established rooting depths of 0, 5, 10, and 15 cm of creeping bentgrass for trial 1B.
Means within columns with the same alphabetic letters are not significantly different at the 0.05 level.

Irrigation Treatments	5 Mar Seeded	12 Mar Wk1	19 Mar Wk2	26 Mar Wk3	2 Apr Wk4	9 Apr Wk5	16 Apr Wk6	23 Apr Wk7
Overhead	N/A	8.3	7.8	7.5	9.0	8.0b	8.5	9.0
0 cm SDI	N/A	8.5	7.3	7.0	9.0	9.0a	9.0	9.0
5 cm SDI	N/A	8.5	7.3	8.3	8.8	9.0a	8.8	9.0
10 cm SDI	N/A	8.5	7.5	6.5	9.0	9.0a	9.0	9.0
15 cm SDI	N/A	8.3	7.3	6.3	9.0	9.0a	9.0	9.0
P- value	N/A	0.9224	0.8371	0.0862	0.4449	<.0001	0.4449	N/S

Trial 1B: Turfgrass height measurements.

There was no significant difference in turfgrass height between treatments for weeks 1 to 4 (Table 1.9). All SDI treatments had significantly higher turfgrass height than the overhead treatment for weeks 5 to 7. The turfgrass height of the creeping bentgrass increased in all treatments after fertigation that was initiated in week 3.

Table 1.9. Turfgrass height measurements (cm) transitioning from overhead to subsurface drip irrigation at established rooting depths of 0, 5, 10, and 15 cm of creeping bentgrass for trial 1B.
Means within columns with the same alphabetic letters are not significantly different at the 0.05 level.

Irrigation Treatments	5 Mar Seeded	12 Mar Wk1	19 Mar Wk2	26 Mar Wk3	2 Apr Wk4	9 Apr Wk5	16 Apr Wk6	23 Apr Wk7
Overhead	N/A	0.3	0.6	0.9	3.6	3.5b	3.8b	3.7b
0 cm SDI	N/A	0.3	0.5	0.7	3.9	6.4a	7.3a	7.3a
5 cm SDI	N/A	0.3	0.7	0.9	4.8	7.1a	8.3a	7.8a
10 cm SDI	N/A	0.3	0.5	0.8	3.8	6.6a	8.8a	8.3a
15 cm SDI	N/A	0.3	0.4	0.7	3.6	7.3a	7.4a	7.9a
P- value	N/A	0.9272	0.5629	0.6186	0.2785	<.0001	0.0021	0.0029

Trial 1B: Soil moisture measurements.

There was no significant difference in soil moisture percentages between treatments except for week 1 (Table 1.10), when, the 10 cm SDI treatment had significantly higher soil moisture percentage than the 0 cm SDI treatment. The soil moisture percentages increased over the duration of the trial for all treatments.

Table 1.10. Soil moisture measurements (%) transitioning from overhead to subsurface drip irrigation at established rooting depths of 0, 5, 10, and 15 cm of creeping bentgrass for trial 1B.
Means within columns with the same alphabetic letters are not significantly different at the 0.05 level.

Irrigation Treatments	5 Mar Seeded	12 Mar Wk1	19 Mar Wk2	26 Mar Wk3	2 Apr Wk4	9 Apr Wk5	16 Apr Wk6	23 Apr Wk7
Overhead	0.9	1.9ab	3.9	2.4	8.7	13.6	8.6	24.6
0 cm SDI	1.3	1.0b	1.8	2.7	6.9	7.9	7.5	6.7
5 cm SDI	1.3	2.1ab	3.1	3.7	8.7	13.4	15.1	16.7
10 cm SDI	1.2	2.8a	3.1	4.5	8.7	9.4	9.2	12.5
15 cm SDI	1.2	1.8ab	2.1	1.9	5.9	7.1	7.0	8.0
P- value	0.3847	0.0192	0.1199	0.0574	0.5300	0.5018	0.2025	0.2035

Discussion

In trial 1A, the overhead irrigation and 15 cm SDI treatments showed similar turfgrass quality and percent turfgrass cover but were poorer than in trial 1B, where the turfgrass quality and percent turfgrass coverage was 100% for all the treatments. The creeping bentgrass failed to germinate in the sand based media for the 0 cm SDI treatment. Capillary (upwards) movement of water is very limited from the emitters in sandy soils which makes it difficult to provide enough moisture at the surface for germination and establishment of creeping bentgrass from seed (Grabow, *et al*., 2008). The 0 cm SDI treatment failed to provide enough moisture for germination; however, in trial 1B, the creeping bentgrass was successful in germinating and establishing in the sand based media for the 0 cm SDI treatment. The difference between trial 1A and 1B might be due to the different time of year they were conducted. Trial 1A was conducted in the summer and trial 1B in the spring, and the higher temperatures in the summer make it more difficult to maintain proper surface moisture with SDI (Weeaks, 2009). It appears that the lower establishment and decreased vegetative growth observed were due to the lack of surface moisture, not a function of rooting depth when SDI was applied (Weeaks, 2009). The lack of surface soil moisture might be attributed to a number of factors in this experiment. Higher temperatures in the greenhouse in summer compared to the spring likely increase evaporation from the soil surface. Similarly, in summer the cooling fans were running more (increase air movement) in the greenhouse which could have attributed to greater soil surface evaporation compared to the spring. Although both trials were conducted in the greenhouse. The internal environment was not the same due to the limited environmental control of the greenhouse. In addition, the limited capillary movement of water from the emitter to the soil surface in the sand based media may have prevented establishment. All three of these factors may have contributed to inadequate surface soil moisture resulting in no establishment for the 0 cm SDI treatment in the summer.

The planting media used did not meet the standards set by the USGA, (2004) which recommends a clay distribution of ≤ 3% for the USGA root zone mix but the media that was used in trial 1A had 10% clay content and trial 1B had 7% clay content. The higher clay content of the media in the spring may have resulted in better establishment compared to the results of Weeaks *et al.*, (2007), who observed no significant establishment of creeping bentgrass in many of the treatments during their study. However, in the summer, the higher clay content failed to contribute to successful establishment of the creeping bentgrass seed.

In trial 1B (Table 1.9), longer shoot growth was significant in the 0, 5, 10, and 15 cm SDI treatments as compared to the control, this was not evident in trial 1A (Table 1.5). The reason for the longer shoot development in SDI treatments compared with overhead treatment is the limited availability of root zone water, which causes the roots to grow deeper. When the roots grow longer, water is easily available from the emitter and results in longer shoot growth. Vertical shoots of turfgrasses that have a rapid extension rate have a tendency to use higher water rates than slow growing or dwarf type grasses because transpiration occurs from the increased leaf surface area (Kim and Beard 1988; Shearman and Beard 1973).

The use of sphagnum peat moss in sand based media leads to faster establishment of “L-93” creeping bentgrass (Simplot, *n.d.*). Sphagnum peat moss at a rate of 10% was used in both trials to achieve maximum establishment; however, Weeaks *et al.*, (2007) used higher amounts in order to achieve higher establishment. Sphagnum peat moss amendment results in faster germination of creeping bentgrass seed than in a coarse sand amendment. An experiment by Simplot, (*n.d.*) on “L-93” creeping bentgrass establishment showed faster cover and good turfgrass quality with amendments like sphagnum peat and reed sedge. Adding sphagnum peat or reed sedge amendments to sand resulted in creeping bentgrass achieving an acceptable establishment rating 24 days after seeding. Similarly, good turfgrass quality and cover were evident in trial 1B compared to trial 1A. This also might be due to the different time of the year. In the experiment of Weeaks *et al.*, (2007), high rates of amendment at 20, 40, and 60 percent by volume peat moss was used to achieve maximum establishment. In the experiment of Weeaks, (2009), peat moss did not perform better than an in-organic product such as Lassenite ATS. However, full establishment was observed in the trial 1B with 10% peat moss.

In trial 1A, the growth of creeping bentgrass was evident in the center of the lysimeters directly over the emitter for the 5 cm SDI treatment (Figure 1.1). Similar results were observed by Weeaks *et al.*, (2007). Maximum establishment of creeping bentgrass in both trials was due to the continual wetting of the surface by providing irrigation three times a day during the initial sowing. The decline in the percent turfgrass cover and turfgrass quality or growth directly over the emitter in the 5 and 10 cm SDI treatments of trial 1A might be due to the transition to SDI earlier (week 2 and week 4 respectively). The 15 cm SDI treatment received overhead irrigation for a longer duration (5 weeks) compared to the 5 and 10 cm SDI treatments. In trial 1A, the 15 cm SDI treatment had significantly higher percent turfgrass cover and turfgrass quality than the 5 and 10 cm SDI treatments because the 15 cm SDI treatment had a more developed root system from overhead irrigation before transitioning to SDI.

The better percent turfgrass cover, turfgrass quality and shoot growth in trial 1B as compared to trial 1A might be due to the addition of macro and micro nutrients via fertigation. The improved growth and quality of turfgrasses to the addition of fertilizer is well documented.

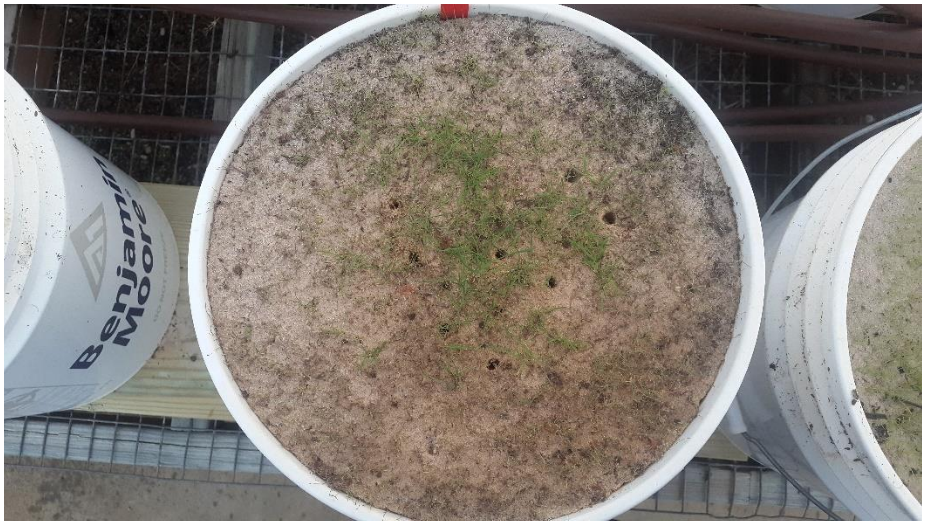

Figure 1.1. Central growth of creeping bentgrass in trial 1A of the 5 cm SDI treatment

Conclusions

In trial 1A of experiment 1, the overhead and 15 cm SDI treatments showed an acceptable percent turfgrass cover and moderate turfgrass quality. The 5 and 10 cm SDI treatments had lower percent turfgrass cover and lower turfgrass quality while the 0 cm SDI treatment failed to establish any turfgrass. In trial 1B, all the treatments had full percent turfgrass cover and high turfgrass quality irrespective of the transitions to SDI. In trial 1A, the turfgrass shoot growth was similar for treatments of established turfgrass, but in trial 1B the turfgrass shoot growth was greater in the SDI treatments compared to the overhead treatment. The soil moisture percentages were higher for the overhead, 10, and 15 cm SDI treatments in trial 1A however, in trial 1B soil moisture percentages were similar for all treatments.

The 15 cm SDI and overhead treatments resulted in similar turfgrass quality irrespective of establishment time. The 5 and 10 cm SDI treatments successfully established seeded creeping bentgrass in the spring, but had a lower quality of turfgrass in the summer. These results indicate that successful establishment of seeded creeping bentgrass with SDI may depend on the time of establishment as the spring 0 cm SDI treatment successfully established seeded creeping bentgrass, but not in the summer.

Experiment 2: Trials 2A and 2B: Establishment of Ultra Dwarf Hybrid Bermudagrass (*C. dactylon x C. transvaalensis*) from sod in sand based systems combining sprinkler and subsurface drip irrigation systems.

Introduction

Sprinkler irrigation is the most common and conventional way of establishing turfgrasses. However, sprinkler irrigation can result in a significant loss of water due to evaporation and run off. Using sprinklers has many disadvantages as worn nozzles on sprinkler heads can affect uniformity of water application (Gross, 2004), and inaccurate spacing between sprinklers and imprecise pressure of the worn sprinkler nozzles reduces the uniformity of water application. Subsurface drip irrigation (SDI) defined as “An application of water below the soil surface through emitters, with discharge rates generally in the same range as drip irrigation” (ASAE, 1999). Using SDI may eliminate many of the inherent problems of sprinkler irrigation. Subsurface drip irrigation users have demonstrated a 50% reduction in water use compared to conventional irrigation systems while still achieving the same plant growth (Pearce, 1994) since subsurface drip minimizes evaporation, runoff and overspray by putting water at the site of plant uptake, the grass's root zone (Hulst, 2000). Unlike other crops, turfgrass yield is not a concern; however, appearance is of the utmost importance. Uniform turfgrass appearance is directly influenced by the type of irrigation systems that are used (Devitt and Miller. 1988). It is difficult to establish bermudagrass from sod in a sand based system by using SDI due to the limited capillary action in sand based soils. Hybrid bermudagrasses are sterile and are only propagated vegetatively by sod and sprigs (Duble *n.d.*).

There are two types of soils which are used in the establishment of turfgrasses: native soils and sand based soils (Beard, 1973). Golf greens are commonly built using the USGA method of construction (USGA, 2004) using coarse (1.0 to 2.0 mm) and medium sand (0.25 to 0.50 mm) as the primary constituent. The USGA allows a wide variety of amendments that can be added to the final root zone mixture. Included in this list are organic amendments such as peat moss, rice hulls, finely ground bark, sawdust, and other properly treated organic wastes (USGA, 2004). The most common organic component is peat moss at a maximum of 20% by volume (USGA, 2004).

Weeaks (2003) accomplished successful establishment of bermudagrass from seed using SDI in a fine-loamy soil. Suarez-Rey *et al.* (2000) compared the response of stolonized bermudagrass in coarse-loamy over sandy soil using SDI and sprinkler irrigation in Arizona. Their results indicated that there was no significant difference in turfgrass quality of bermudagrass between SDI and sprinkler treatments.

No research has been conducted on the establishment of bermudagrass from sod by using sprinkler irrigation then transitioning to SDI. The purpose of this research was to evaluate the transition from sprinkler to SDI at established rooting depths of 0, 5, 10, and 15 cm of sodded ultra dwarf hybrid bermudagrass in sand based media.

Materials and Methods

Trial 2A was conducted in an open area between the Stephen F. Austin State University (SFASU) Soccer Field and La Nana Creek and trial 2B was in the glass greenhouse located at SFASU in Nacogdoches, Texas. Trial 2A was initiated on 27 July 2017 and Trial 2B on 26 March 2018. Both were conducted for eight weeks to evaluate the effectiveness of sodded ultra dwarf hybrid bermudagrass establishment in sand based systems following a transition from overhead irrigation to SDI. Both trials consisted of five treatments with four replicates. Treatments consisted of a control (overhead irrigation only) and four treatments that transitioned from overhead irrigation to SDI when the roots reached a depth of 0, 5, 10, and 15 cm. The sand for trial 2A was obtained from David Kolb Excavation, Nacogdoches, TX and the sand for trial 2B was obtained from Crown Colony Country Club, Lufkin, TX. Sand media for both trials was amended with 10% peat moss. Soil samples were collected and analyzed for soil texture and nutrient concentrations at the SFASU Soil, Plant and Water Analysis Laboratory (Tables 4.1 and 4.2). The SDI used for these two trials was a Rain Bird XFD-100 Series drip tubing with a flow rate of 1 L hr^{-1} (Rain Bird Corporation, CA). There were 21 buckets (19 liter) used in each trial. Each bucket was considered a lysimeter. One was used to determine rooting depth while the other 20 lysimeters were used for the specific treatments. Each lysimeter was 38 cm tall and 30 cm (28 cm inside rim) in diameter with a surface area of 0.061 m^2; all had a single 0.6 cm diameter hole drilled in the side near the bottom of the container for drainage. Holes (17 mm diameter) were drilled into the side of the lysimeter at a depth of 15 cm from the top to facilitate the drip line with a single emitter. The drip tubing emitter orifice was positioned directly in the center of the lysimeter. The ends of the tubing of each lysimeter were plumbed together by using blank tubing to carry water to the 4 lysimeters in each treatment. The opposite side of the tubing was capped by folding over the tubing to avoid any leakage of water. A 2.5 cm layer of pea gravel was used to cover the bottom of each lysimeter.

Table 2.1. Soil texture analysis of trial 2A and trial 2B sand.

	Trial 2A	Trial 2B
	%	%
Clay (< 2µm)	10	07
Silt (2 - 50µm)	03	03
Sand (50 - 2000µm)	87	90

Table 2.2. Soil chemical analysis of trial 2A and trial 2B sand.

	Trial 2A	Trial 2B
pH	7.82	7.89
Nutrients	(mg L^{-1})	(mg L^{-1})
Na	46.313	54.968
P	3.471	1.673
K	12.611	17.346
Ca	53.593	175.129
Mg	10.932	19.253
S	13.042	81.301
Fe	4.039	8.736
Mn	0.101	0.653
Zn	0.106	0.301
Cu	0.041	0.045

Media was prepared in a drum-type mixer by mixing 90% sand with 10% peat moss volume to volume to ensure a homogenous mixture. Once well blended, media was placed into each lysimeter and drip tubing was inserted into the sidewall of each lysimeter. Before placing the sod, all lysimeters were well watered by overhead irrigation to settle the sand. Ultra dwarf hybrid bermudagrass ‘TifEagle’ (*C. dactylon x C. transvaalensis*) was obtained from Ralph Sanders Sod Farm (Cleveland, TX) and cut to fully cover each lysimeter. After placement, each lysimeter was irrigated uniformly from the top.

Irrigation cycles varied based on plant development. After sowing, all lysimeters for the overhead, 5, 10, and 15 cm SDI treatments were irrigated overhead. The control treatment in both trials was the application of overhead irrigation throughout the trials. Sprinkler irrigation was simulated as overhead irrigation using a handheld spray nozzle. It was not possible to install the sprinkler irrigation systems to uniformly irrigate individual lysimeters. The lysimeters of trial 2A received 185 mm of rainfall the week of 24 August 2017 from hurricane Harvey (US Climate Data).

The SDI was provided only to the 0 cm at SDI treatment three times a day during the 1st week while sprinkler irrigation was applied three times a day in both trials to all other lysimeters. The timing of irrigation was 10 am, 2 pm and 6 pm. Overhead irrigation was applied two times (10 am and 6 pm) a day after week 1. Beginning in week 3, all the lysimeters were irrigated once a day (10 am) until the end of the experiment. The 5, 10, and 15 cm SDI treatments were irrigated with overhead irrigation until the root length reached a depth of 5, 10, 15 cm, respectively, then switched to SDI for the remainder of the trial. Roots reached a depth of 5, 10, and 15 cm for the 5, 10, and 15 cm

SDI treatments in weeks 2, 4, and 5 respectively. The root length was determined weekly from the sample lysimeter in both trials by collecting core samples with a soil probe.

While trial 2A did not receive any fertilization, fertilizer was applied in trial 2B via fertigation beginning 3 weeks after sod placement. Each lysimeter received 473ml of 250mg N L^{-1} water soluble fertilizer solution weekly. The fertilizer was Peter's Professional 20N-4P-17K fertilizer including magnesium-0.15%, boron-0.0125%, copper-0.0125%, iron-0.0500%, manganese-0.0250%, molybdenum-0.0050%, and zinc-0.0250% (ICL, Dublin, OH). Data was collected weekly for turfgrass percent green cover, turfgrass quality, and turfgrass growth (shoot length). The volumetric soil moisture content of each lysimeter was determined weekly using a TDR 100 Soil Moisture Meter (Spectrum Technologies Inc., Plainfield, IL) with a sensor length of 12 cm by inserting the sensor into the media approximately 5 to 10 cm away from the drip emitter. Turfgrass growth was measured from the surface of the lysimeter rim. After weekly measurements of shoot growth, the shoots were removed from the lysimeters rim with a scissor. The rating system for visual observations of turfgrass percent green cover that was used by the National Turfgrass Evaluation Program (NTEP): 1= no green coverage, 5= 50% green coverage and 9=100% green coverage The visual observations of turf quality was based on a scale of 1 poorest to 9 best (NTEP, 2004).

The experimental design was a randomized complete block design (RCBD) with 4 replications. The data was analyzed using SAS 9.2 (Cary, NC) via One-Way ANOVA.

The GLM model was used for data analysis. Tukey's studentized range test (HSD) was used for means separation where differences occurred at the 5% significant level.

Results

Trial 2A: Visual turfgrass percent green cover ratings.

The "TifEagle" ultra dwarf hybrid bermudagrass showed no significant difference in turfgrass percent green cover between the overhead, 0, 5, 10, and 15 cm SDI treatments (Table 2.3). The turfgrass green cover was 100% at the start of trial for all treatments and greater than 50% at the end of the trial, although, there was no significant difference between treatments over the duration of the trial.

Table 2.3 Percent green cover ratings transitioning from overhead to subsurface drip irrigation at established rooting depths of 0, 5, 10, and 15 cm of ultra dwarf hybrid bermudagrass for trial 2A.

Irrigation Treatments	27 July Initial	03 Aug Wk1	10 Aug Wk2	17 Aug Wk3	24 Aug Wk4	31 Aug Wk5	07 Sep Wk6	14 Sep Wk7
Overhead	9.0	8.0	8.8	7.8	7.0	7.3	6.8	6.3
0 cm SDI	9.0	6.5	7.0	7.3	7.5	7.0	6.3	5.5
5 cm SDI	9.0	8.5	8.3	7.3	7.0	6.0	6.3	5.5
10 cm SDI	9.0	8.5	8.3	6.8	6.8	7.0	6.5	6.3
15 cm SDI	9.0	8.3	8.0	7.5	7.0	7.0	6.5	6.8
P- value	NS	0.4613	0.3537	0.8067	0.8899	0.0625	0.9242	0.5066

Trial 2A: Visual turfgrass quality ratings.

The turfgrass quality of the "TifEagle" ultra dwarf hybrid bermudagrass grown in sand based media showed no significant difference between treatments (Table 2.4). The turfgrass quality was best at the start of trial but declined over the duration of the trial for all treatments.

Table 2.4. Turfgrass quality ratings transitioning from overhead to subsurface drip irrigation at established rooting depths of 0, 5, 10, and 15 cm of ultra dwarf hybrid bermudagrass for trial 2A.

Irrigation Treatments	27 July Initial	03 Aug Wk02	10 Aug Wk03	17 Aug Wk04	24 Aug Wk05	31 Aug Wk06	07 Sep Wk07	14 Sep Wk08
Overhead	9.0	9.0	8.5	8.0	6.8	7.0	6.8	5.8
0 cm SDI	9.0	6.3	7.0	7.5	7.0	5.5	5.5	5.8
5 cm SDI	9.0	8.0	8.0	8.0	6.5	5.8	6.3	5.8
10 cm SDI	9.0	9.0	8.0	8.0	6.8	6.5	6.8	6.3
15 cm SDI	9.0	8.0	8.3	7.3	6.8	6.5	6.3	6.3
P- value	N/S	0.1993	0.4857	0.6178	0.9933	0.0857	0.1340	0.8323

Trial 2A: Turfgrass height measurements.

There was no significant difference in turfgrass height between overhead and SDI treatments except in weeks 4 and 5. In week 4, the 0 and 10 cm SDI treatments had significantly higher turfgrass height than the overhead treatment, and the 5 and 15 cm SDI treatments had similar turfgrass height. The 0 and 5 cm SDI treatments had significantly higher turfgrass height than the overhead treatment in week 5. The 10 and 15 cm SDI treatments had lower turfgrass height, but were not significantly different from the 0 and 5 cm SDI treatments. The turfgrass height remained similar for all the treatments over time (Table 2.5).

Table 2.5. Turfgrass height measurements (cm) transitioning from overhead to subsurface drip irrigation at established rooting depths of 0, 5, 10, and 15 cm of ultra dwarf hybrid bermudagrass for trial 2A.
Means within columns with the same alphabetic letters are not significantly different at the 0.05 level

Irrigation Treatments	27 July Initial	03 Aug Wk1	10 Aug Wk2	17 Aug Wk3	24 Aug Wk4	31 Aug Wk5	07 Sep Wk6	14 Sep Wk7
Overhead	N/A	0.9	0.9	1.0	1.0b	1.0b	1.2	1.0
0 cm SDI	N/A	1.1	1.1	1.3	1.3a	1.7a	1.3	1.1
5 cm SDI	N/A	1.1	1.2	1.3	1.1ab	1.7a	1.4	1.2
10 cm SDI	N/A	1.0	1.1	1.1	1.3a	1.3ab	1.1	0.9
15 cm SDI	N/A	1.0	1.3	1.3	1.2ab	1.1ab	1.1	1.0
P- value	N/A	0.5474	0.0953	0.4129	0.0125	0.0092	0.5930	0.4939

Trial 2A: Soil moisture measurements.

There was a significant difference in soil moisture percentages for weeks 2, 4, 6, and 7 between the overhead and SDI treatments (Table 2.6). In week 2, the 15 cm SDI treatment had significantly higher soil moisture percentage than the 0, 5, 10 cm SDI treatments. The 15 cm SDI treatment had a significantly higher soil moisture percentage than the overhead and 0 cm SDI treatment in week 4. In week 6, the overhead, 10 and 15 cm SDI treatments had significantly higher soil moisture percentages than the 0 and 5 cm SDI treatments. The overhead and 15 cm SDI treatments had significantly higher soil moisture percentages than the 0 cm SDI treatment and the 5 and 10 cm SDI treatments had similar soil moisture percentages compared with overhead, 0 and 15 cm SDI treatments in week 7.

Table 2.6. Soil moisture measurements (%) transitioning from overhead to subsurface drip irrigation at established rooting depths of 0, 5, 10, and 15 cm of ultra dwarf hybrid bermudagrass for trial 2A.
Means within columns with the same alphabetic letters are not significantly different at the 0.05 level

Irrigation Treatments	27 July Initial	03 Aug Wk1	10 Aug Wk2	17 Aug Wk3	24 Aug Wk4	31 Aug Wk5	07 Sep Wk6	14 Sep Wk7
Overhead	14.0	15.0	15.0ab	12.0	15.0b	14.0	14.4a	14.0a
0 cm SDI	14.0	15.0	13.0b	13.0	14.3b	11.0	10.0b	9.0b
5 cm SDI	14.0	16.0	13.0b	14.0	16.0ab	12.0	11.0b	11.1ab
10 cm SDI	14.2	15.0	14.2b	14.0	16.2ab	13.2	14.0a	12.0ab
15 cm SDI	14.0	15.3	16.1a	14.0	17.2a	15.0	15.0a	14.4a
P- value	0.9690	0.9444	0.0019	0.1582	0.0271	0.0538	0.0018	0.0015

Trial 2B: Visual percent green cover ratings.

In the greenhouse trial 1B, the “TifEagle” ultra dwarf hybrid bermudagrass grown in sand based media had no significant difference and exhibited the same turfgrass percent green cover in all treatments throughout the trial except week 1 (Table 2.7). In this trial in week 1, the overhead and 10 cm SDI treatments had significantly more green cover than the 0 cm SDI treatment. The 5 and 15 cm SDI treatments had the same turfgrass percent green cover compared to overhead, 0 and 10 cm SDI treatments. At the end of the trial, all the treatments including overhead achieved 100% turfgrass green cover.

Table 2.7. Percent green cover ratings transitioning from overhead to subsurface drip irrigation at established rooting depths of 0, 5, 10, and 15 cm of ultra dwarf hybrid bermudagrass for trial 2B.
Means within columns with the same alphabetic letters are not significantly different at the 0.05 level

Irrigation Treatments	26 Mar Initial	04 Apr Wk1	09 Apr Wk2	16 Apr Wk3	23 Apr Wk4	30 Apr Wk5	07 May Wk6	14 May Wk7
Overhead	9.0	7.8a[z]	7.8	7.3	8.0	9.0	9.0	9.0
0 cm SDI	9.0	6.0b	7.0	8.0	9.0	8.8	9.0	9.0
5 cm SDI	9.0	7.0ab	8.0	8.0	9.0	9.0	9.0	9.0
10 cm SDI	9.0	8.0a	8.0	8.0	8.2	8.8	9.0	9.0
15 cm SDI	9.0	6.8ab	8.0	8.0	8.3	8.8	9.0	9.0
P- value	N/S	0.0092	0.0318	0.3420	0.2338	0.7166	N/S	N/S

Trial 2B: Visual turfgrass quality ratings.

There was no significant difference in turfgrass quality ratings between treatments throughout the trial except week 2 when the turfgrass quality was significantly better for overhead and 10 cm SDI treatments compared with the 0 cm SDI treatment (Table 2.8). The 5 and 15 cm SDI treatments had similar turfgrass quality, but not significantly different from other treatments. All the treatments had a high turfgrass quality irrespective of treatments over time.

Table 2.8. Turfgrass quality ratings transitioning from overhead to subsurface drip irrigation at established rooting depths of 0, 5, 10, and 15 cm of ultra dwarf hybrid bermudagrass for trial 2B.
Means within columns with the same alphabetic letters are not significantly different at the 0.05 level

Irrigation Treatments	26 Mar Initial	04 Apr Wk1	09 Apr Wk2	16 Apr Wk3	23 Apr Wk4	30 Apr Wk5	07 May Wk6	14 May Wk7
Overhead	8.0	7.0	8.8a[z]	8.0	8.3	8.5	8.8	8.8
0 cm SDI	8.0	6.0	7.0b	8.3	8.8	8.0	8.5	8.8
5 cm SDI	8.0	8.0	8.3ab	8.3	9.0	8.5	8.8	8.8
10 cm SDI	8.0	7.0	8.8a	8.0	8.5	8.5	8.5	8.5
15 cm SDI	8.0	7.0	8.5ab	8.0	8.3	8.8	8.5	8.5
P- value	N/S	0.1283	0.0215	0.5127	0.5127	0.6114	0.8899	0.8899

Trial 2B: Turfgrass height measurement and soil moisture measurements.

In the greenhouse trial 2B, all treatments had similar turfgrass height throughout the trial without any significant difference between treatments. In week 4, after fertigation, the turfgrass height started to increase for all treatments (Table 2.9). There was also no significant difference in the soil moisture percentages between treatments throughout the trial (Table 2.10).

Table 2.9. Turfgrass height measurements (cm) transitioning from overhead to subsurface drip irrigation at established rooting depths of 0, 5, 10, and 15 cm of ultra dwarf hybrid bermudagrass for trial 2B.

Irrigation Treatments	26 Mar Initial	04 Apr Wk1	09 Apr Wk2	16 Apr Wk3	23 Apr Wk4	30 Apr Wk5	07 May Wk6	14 May Wk7
Overhead	N/A	1.0	2.5	1.2	1.8	3.0	3.2	3.1
0 cm SDI	N/A	1.0	1.0	1.3	1.4	2.3	4.0	4.0
5 cm SDI	N/A	1.2	2.0	1.3	2.0	3.0	4.0	4.0
10 cm SDI	N/A	1.0	2.0	1.2	2.0	2.3	4.0	4.0
15 cm SDI	N/A	1.0	1.2	1.4	2.0	3.0	4.0	4.0
P- value	N/A	0.0960	0.3495	0.7688	0.4556	0.5424	0.8190	0.5933

Table 2.10. Soil moisture measurements (%) transitioning from overhead to subsurface drip irrigation at established rooting depths of 0, 5, 10, and 15 cm of ultra dwarf hybrid bermudagrass for trial 2B.

Irrigation Treatments	27 July Initial	03 Aug Wk1	10 Aug Wk2	17 Aug Wk3	24 Aug Wk4	31 Aug Wk5	07 Sep Wk6	14 Sep Wk7
Overhead	15.1	14.0	13.3	16.0	16.0	16.4	14.0	15.0
0 cm SDI	15.0	10.2	13.2	17.0	19.0	16.1	17.0	19.0
5 cm SDI	16.0	17.0	16.2	13.0	13.1	12.2	13.0	16.0
10 cm SDI	14.0	17.1	24.0	14.4	19.2	17.0	17.0	18.1
15 cm SDI	14.0	17.0	18.1	21.0	21.1	21.0	19.4	17.0
P- value	0.6171	0.0770	0.1894	0.4886	0.6241	0.5314	0.5595	0.5461

Discussion

Capillary (upwards) movement of water from the subsurface drip emitter to the soil surface is limited in sandy soils. This limitation also contributes to reduce lateral water movement and makes it difficult to provide enough moisture for establishment when using sod in sand based soils (Grabow, *et al*., 2008). The trial 2B showed 100% turfgrass green cover and better turfgrass quality compared to the field trial 2A as the greenhouse maintains a constant environment compared to field conditions. For ultra dwarf hybrid bermudagrass, there were no significant difference observed in terms of turfgrass quality and turfgrass percent green cover between overhead and SDI treatments during trials 2A and 2B. Similarly, Suárez-Rey *et al*., (2000) found no differences in turfgrass quality and turfgrass percent green cover of stolonized bermudagrass in coarse-loamy over sandy soil when using SDI after 24 days of applying sprinkler irrigation during establishment.

Longer vertical shoots developed in trial 2B compared with the open field trial 2A. The application of water soluble fertilizer in the greenhouse trial 2B might be the cause of longer shoot development, especially after initial establishment, as no fertilization was applied in the field trial 2A. Vertical shoots of turfgrasses that have a rapid extension rate have a tendency to use higher water rates than slow growing or dwarf type grass because of increased transpiration from the increased leaf surface area (Kim and Beard 1988; Shearman and Beard 1973).

Serena *et al.*, (2015) found that sprinkler irrigated plots established fastest than SDI plots regardless of time of sodding. Both trials showed no significant differences in achieving turfgrass percent green cover for overhead versus SDI treatments (Tables 2.1 and 2.2).

Soil moisture percentage was significantly lower in trial 2A than trial 2B. Trial 2A was performed in the field during summer months while trial 2B was performed in the greenhouse during spring months. The turfgrass in field trial 2A likely consumed more water compared to the greenhouse trial 2B due to higher transpiration rates during summer months in the field.

Two different sources of sand were used in the two trials and the media were not consistent with the recommendations of the USGA which recommends a clay distribution of ≤ 3% for the USGA root zone mix but the media that was used in trial 2A had 10% and 2B had 7% clay content, respectively (Table 4.1). This higher clay content could have increased water capillary movement resulting in the successful establishment in both trials. Covering the media with sod likely resulted in a reduction in evaporation. The type of soil attached with the sod might cause better capillary movement into the sod for SDI. Similarly, the soil type associated with sod may enhance capillary movement from the sand based media.

Conclusions

In trial 2A, all treatments had a similar turfgrass percent green cover and better turfgrass quality irrespective of the transitions to SDI in the sand based media, and in trial 2B, all treatments had full turfgrass percent green cover and high turfgrass quality irrespective of the transitions to SDI in the sand based media. The turfgrass height in both trials was similar in SDI treatments as compared with the overhead treatment. Trial 2B had much greater turfgrass height as compared to trial 1A. The soil moisture percentage was slightly higher in the overhead treatment compared to the SDI treatments in trial 2A but more in SDI treatments in trial 2B.

Trial 2A was performed in the field during the hotter months of summer while trial 2B was conducted during the spring in the greenhouse. The results suggest that ultra dwarf hybrid bermudagrass can be established with full turfgrass percent green cover and high turfgrass quality from sod by using SDI in sand based media during the spring in the greenhouse. In the summer, ultra dwarf hybrid bermudagrass can also be established from sod in sand based media by using SDI in the field, but may result in reduced turfgrass quality and growth.

Summary

The results of the experiment 1 demonstrated that creeping bentgrass can be established from seed in summer or spring by using SDI in sand based systems. In summer, rooting depth at the time of transitions for SDI is critical. In summer, the 15 cm SDI treatment produced good percent turfgrass cover and turfgrass quality similar to overhead irrigation. In the spring, creeping bentgrass can be established with full turfgrass percent cover and good turfgrass quality without considering the rooting depth at the time of transitions. For seeded creeping bentgrass establishment in the summer, the transition to SDI should not be until a rooting depth of 15 cm has occurred.

Ultra dwarf hybrid bermudagrass can be successfully established from sod in both summer and spring using SDI in sand based systems without critically looking the rooting depth at the time of transitions to SDI.

The results of these experiments provide preliminary information for the successful establishment of seeded creeping bentgrass and sodded ultra dwarf hybrid bermudagrass using subsurface drip irrigation in sand based media. Further research is needed to evaluate establishment and turfgrass quality in larger plots sizes that can determine emitter and dripline spacing recommendations. Likewise, evaluation of other establishment methods such as stolons, sprigs and washed sod should be evaluated in sand based systems.

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Vitae

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