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IMPACT OF PREEMERGENT HERBICIDES, MOWING HEIGHT, AND FERTILIZATION ON CENTIPEDEGRASS ROOT ARCHITECTURE AND DROUGHT TOLERANCE

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IMPACT OF PREEMERGENT HERBICIDES, MOWING HEIGHT, AND FERTILIZATION ON CENTIPEDEGRASS ROOT ARCHITECTURE AND DROUGHT TOLERANCE

A Thesis

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by
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For Cubby

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Abstract

Mowing, N fertilization and the application of preemergence herbicides (PRE) are cultural practices performed on centipedegrass to improve overall turf quality. It is posited that increasing mowing height and application of fertilizers can lead to greater turfgrass rooting and increase drought survival; while the application of PRE is reported to potentially have negative impacts on rooting. At two locations in Louisiana, studies examining the effects of these practices on centipedegrass rooting and drought tolerance were conducted.

In the first 11-week study conducted, centipedegrass was treated with dithiopyr, pendimethalin, prodiamine, simazine, or indaziflam at the manufacturers' labeled rates. During the 11-wk experiments, roots were harvested at upper and lower contiguous soil depths of 7.5 cm and analyzed for root length (RL), surface area (SA), average diameter (AD), length volume^{-1} (LPV), and root mass (RM). Across all treatments and soil depths, PRE did not alter rooting compared to controls with the exception of AD for simazine-treated centipedegrass at 0.397 mm compared to 0.338 and 0.341mm for prodiamine and indaziflam, respectively. At 11 wks., cores were harvested and subjected to a 28 d dry-down period. Centipedegrass maintained acceptable leaf color for 13 days before complete leaf firing occurred at 20 days. A single application of PRE to mature centipedegrass during early spring did not alter rooting or drought tolerance compared to controls.

In the second study, centipedegrass was maintained at one of four mowing heights (2.5, 5, 7.5 and 10 cm) and subjected to fertilization or no fertilization. During the 29-wk experiments, roots were harvested and analyzed as above and subjected to a mid-summer 36-day drought simulation. All centipedegrass in these experiments exhibited a pattern of increased leaf firing over the drought simulation with unfertilized centipedegrass maintaining acceptable leaf color

(≥5) for 19 days at 5.9 compared to 4.8 when fertilized. Rooting parameter measurements across all mowing heights and soil depths initially declined from spring into summer then increased in fall. This, in conjunction with the lack of changes in rooting from alterations in cultural practices, indicates soil temperature may be a significant factor in centipedegrass rooting.

Chapter 1. Literature Review

1.1. Introduction

Many homeowners across the country spend part of their free time caring for and grooming their lawns. They are provided with a myriad of products and reams of information and advice on how best to care for that expanse of turfgrass fronting their homes. Homeowners or landscapers that are more curious and diligent may wonder if preemergence herbicides harm the turf in any way, what impact mowing height may have on the quality and appearance of their lawn, does applying nitrogen fertilizers to the lawn alter more than just the top growth of turf in any way, do any of these cultural practices benefit turfgrass survival during periods of drought? These two studies attempt to address these questions when these practices are applied to the care and maintenance of centipedegrass in particular, a turfgrass species commonly grown in the Southeastern United States.

Islam and Hirata (2005) characterize centipedegrass [*Eremochloa ophiuroides* (Munro.) Hack.] as a native grass species from southern and central China, which was first introduced in the United States from seeds collected by Frank N. Meyer in 1916. Centipedegrass is a warm-season (C_4) perennial turfgrass (Beard, 1973) that is commonly grown in the Southern United States in lawns, parks, golf course roughs and as a utility turf along roadsides and public right of ways (McCarty et al., 1986). Sometimes known as “poor man’s grass” or “lazy man’s grass,” centipedegrass is often described as requiring less management and fertilization compared to other warm-season turfgrass species (Hanna, 1995).

In general, warm-season turfgrass species thrive at air temperatures between 27 and 35 ˚C; can be mowed shorter; are more deeply rooted; and exhibit greater drought, heat and wear tolerances; but are susceptible to low temperatures stresses compared to cool-season turfgrass species (Beard, 1973). Flora of China describe centipedegrass as a stoloniferous (Hitchcock, 1951), mat-forming perennial grass with prostrate to slightly ascending culms reaching a height of about 20 cm with flowering shouts 15-30 cm tall appearing from June through October (Hitchcock, 1951). Its leaf sheaths are keeled and overlap at the base and hairy at the mouth (Hitchcock, 1951). The leaf blades are flat (up to 10 cm long and 0.4 cm wide), usually glabrous and rounded at the leaf tip (Hitchcock, 1951). The inflorescence is an erect or slightly curved raceme (4-6 cm) with narrowly club-shaped rachides (Hitchcock, 1951). Additionally, this grass is a slow growing turfgrass species with a medium to course leaf texture, medium green color, with medium to high shoot density with short, thick, leafy stolons (Beard, 1973). Its stolons have short internodes that allow it to form a low, dense, prostrate mat with relatively low, inconspicuous seed heads (Beard, 1973).

With excellent heat hardiness but very poor low temperature hardiness and variable drought resistance (though Carrow (1994) ranks it medium to high in drought resistance), centipedegrass has an intermediate tolerance for shade, poor salt tolerance, wear tolerance and recuperative potential (Beard, 1973). Centipedegrass is adapted to acidic and infertile soil conditions, preferring a soil pH of 5.5, and will adapt to most soil textures except course textured sands (Beard, 1973), which are known to dry out quickly during drought condition or drain too quickly when irrigated, leaching away nutrients (Emmons, 2008).

Centipedegrass can be propagated by seed or vegetative methods including sprigs, plugs and sod (Emmons, 2004). It is recommended that centipedegrass be maintained at a mowing height of 2.5-5 cm and fertilized at 4.5-13.6 kg N ha $^{-1}$ month $^{-1}$ during the growing season (Beard, 1973). Once the home lawn is established it is mowed weekly, might require fertilization once or twice per year, can be irrigated during drought periods and treated for pests as needed (Beard and Kenna, 2008). While relatively insect and disease free, centipedegrass is susceptible to brown patch (*Rhizoctonia solani*), dollar spot (*Sclerotina homoeocarpa*), and nematode injury (Beard, 1973).

1.2. Preemergence Herbicides Effect on Turfgrass Rooting

To control turfgrass weed encroachment, homeowners and turfgrass managers utilize cultural practices as well as available pesticides. Presently, over 180 different chemicals are registered for use in the United States with herbicides making up 60 percent of the total pesticides (Murphy, 1999). Herbicides are chemicals that target several or specific biochemical reactions within a weed through affecting processes involving photosynthesis, amino acid and protein synthesis, cell division, cell wall biosynthesis, cell wall integrity, pigment synthesis, growth regulation, growth inhibition and/or nitrogen metabolism (Murphy, 1999). Herbicides can also be categorized as pre- or post- emergence herbicides. Preemergence herbicides (PRE) are applied prior to a weed germinating and emerging from the soil. As the seed germinates and then grows, the herbicide disrupts plant growth to kill the weed. For example, herbicides containing dinitroanilines are used in turfgrasses to control annual grasses and certain annual broadleaf weeds prior to emergence, but have limited post emergence activity (Murphy, 1999). The benefits of preemergence herbicides include the reduction in competition for light, soil moisture, soil nutrients and carbon dioxide and a uniformity in turfgrass sward disrupted by weeds that often differ in leaf width and shape, growth habit and color (Beard, 1973). In contrast, postemergence herbicides are applied once the weed is visible within the turfgrass canopy.

In addition to controlling weed encroachment in turfgrass, PRE have also been reported to affect turfgrass growth. The PRE, pendimentalin and prodiamine, are dinitroanilines known to disrupt turfgrass root and shoot growth by inhibiting cell division which impacts lateral root development causing root clubbing – the shortening and thickening of root tips (Murphy, 1999). Simazine, which belongs to the triazine family of herbicides, is used to control annual bluegrass and annual broadleaf weeds in most warm-season turfgrasses except bahiagrass [*Paspalum notatum* (Fluegge)] (Murphy, 1999). Simazine is taken up by the plants through their roots and quickly translocated and inhibit electron transport in the light-dependent phase of photosynthesis, thus starving the weeds of photosynthates (Murphy, 1999). Dithiopyr is also used as a PRE herbicide to control annual grass and broadleaf weeds in turfgrass and is readily absorbed by roots, and to some degree by leaves accumulating in the meristematic regions, and does not translocate (Murphy, 1999). Dithiopyr inhibits cell division causing root clubbing (Murphy, 1999; Armbruster et al., 1991). Indaziflam, an alkylalzine, is used to prevent cell division of developing root tips for some germinating grass and broadleaf weeds by cellulose inhibition thus disrupting cell wall biosynthesis (UC Davis; Brabham, et al., 2014). Symptoms on grass species include short, swollen coleoptiles on grass species and swollen hypocotyls on broadleaf species causing these plants to be stunted (Oregon State Univ., 2016). Fishel and Coats (1993) working with bermudagrass [*Cynodon dactylon* (L.) Pers.] grown in sandy clay loam and fine sandy loam found application of dithiopyr at 6 ppb decreased root weight in the sandy clay loam soil, but required at least twice that amount to decrease root weight in very fine sandy loam. Similar results were found with prodiamine, while pendimethalin required applications of at least 96 ppb to reduce root weight (Fishel and Cotes, 1993). Landschoot, et al. (1993) working with Kentucky bluegrass [*Poa pratensis* (L.)] and tall fescue [*Festuca arundinacea* (Schreb.)] grown in silt loam and treated with dithiopyr, pendimethalin and prodiamine at application rates of 0.4, 1.7 and 0.6 kg ha^{-1}, respectively, found that while greenhouse studies indicated a reduction in root weights compared to the control, no differences in root weights were found in the field when these treatments were applied to established stands of these turfgrasses. Although, Fagerness et al. (2002) working with bermudagrass and zoysiagrass [*Zoysia japoncica* (Steud.)], found that preemergence applications of prodiamine, dithiopyr and pendimethalin at rates of 1.1, 0.6 and 3.4 kg ha^{-1}, respectively, may negatively impact the reestablishment of warm-season turfgrasses in areas prone to winter injury. Greenhouse studies performed by McCarty et al. (1995), found when St. Augustingrass [*Stenotaphrum secundatum* (Walt.) Kuntze] sod was placed on soil treated with dithiopyr and pendimethalin, 0.4 or 0.8 kg ai ha $^{-1}$ and 1.1 or 2.2 kg ai ha $^{-1}$, respectively, root biomass was decreased 70% or more and 30 to 65% with simazine applied at 1.1 or 2.2 kg ai ha^{-1}. When fall applications of indaziflam at a rate of 17.5 kg ai ha^{-1} to spring establishments of bermudagrass, c.v. 'Tifway'; centipedegrass, c.v. 'TifBlair'; St. Augustinegrass, c.v. 'Palmetto'; zoysiagrass, c.v. 'Jamur' plugs, sprigs and/or seed, results were similar to the non-treated control (Gozmez de Barreda et al. (2013). But when these rates were increased to 35, 70, and 140 g ai ha^{-1} bermudagrass seed establishment diminished up to 50% (Gomez de Barreda, et al. (2013). The impact of prodiamine and indaziflam on root morphology was shown to decrease in soils with higher organic matter content compared to soils with high sand content (Jones et al., 2013).

1.3. Mowing

Mowing is a primary turfgrass cultural practice that defoliates the plant particularly the upper portion of leaf tissue. This practice impacts both the physiology and development of the turfgrass plants (Beard, 1973). Implementing mowing can alter the growth habit of turfgrass with prostrate or tillering growth becoming enhanced. When the leaf tips are cut, regrowth occurs from intercalary meristematic tissue located at the base of internodes, sheaths and blades

(Oregon State Univ., 2016). Close mowing within the tolerance range for a given turfgrass species increases tillering and shoot density and overall quality while decreasing the overall size of individual plants (Beard, 1973). Mowing below tolerance results in a reduction of carbohydrate synthesis and a depletion of carbohydrate stores as shoot growth rate increases to reestablish photosynthetic tissue and results in a reduction in the depth, extent and total quantity of turfgrass roots (Beard, 1973; Adams et al., 1974). Moderate defoliation stimulates rhizome and stolon development and sod formation, but excessive defoliation restricts this development as well as reducing root diameter, number of root hairs, number of root protoxylem elements and root initiation rates (Robertson, 1933; Biswell and Weaver, 1933; Parker and Samson, 1930; Harrison, 1931). Fagerness and Yelventon (2001) showed a 36% decrease in root biomass when ‘Penncross’ creeping bentgrass [(*Agrostis stolonifera* (L.)] mowing height was reduced from 4.4 to 3.2 mm. Working with ‘Crenshaw’ and Penncross’ varieties of creeping bentgrass, Liu and Huang (2002) demonstrated decreasing mowing height from 4 to 3 mm increased root mortality and decreased new root production. When half or more of the foliage is removed from cool- and warm-season grass species, of either bunch, rhizomatous or stoloniferous types, root growth stopped for periods from 25 to 45 days during the growing season (Crider, 1954). Harrison (1931) working with Kentucky bluegrass (*Poa pratensis* (L.)], red fescue (*Festura rubra* (L.)] and Colonial bentgrass [(*Agrostis capillaris* (L.)] mowed at 1.27, 3.81 and 7.62 cm and fertilized with nitrogen, nitrogen-phosphorus, nitrogen-potassium and nitrogen-phosphorus-potassium found the shorter the grass was cut the smaller the quantity of roots was produced, different species responded differently to mowing treatments, N-fertilizers did not cause an increases in root production to compensate for a lack of top growth and that morbidity in turfgrass was not due to removing buds when mowing, but due to a gradual carbohydrate starvation.

1.4. Nitrogen Fertilization

The large surface area associated with a turfgrasses' extensive fibrous root systems is suited for the uptake of nitrogen and other essential elements. Nitrogen, which constitutes 3 to 6% of turfgrass dry matter, is a vital component of chlorophyll, amino acids and proteins, nucleic acids, and enzymes that affect shoot growth, root growth, shoot density, leaf color, disease resistance, tolerance to heat, cold and drought stresses, recuperative potential and competitiveness within a turfgrass sward (Beard, 1973). Since shoots have priority over roots for available carbohydrates, excessive nitrogen levels can limit rooting thus impairing nutrient and water uptake while increasing susceptibility to environmental stresses (Beard, 1973).

Toler et al. (2007), reported optimal centipedegrass color is achieved when N rates of 97.6 and 195.2 kg ha^{-1} were applied during the growing season. But, over fertilization can lead to "centipedegrass decline" making the turfgrass weaker and susceptible to fungal attack (Trenholm and Unruh, 2006). Adams et al. (1974) found root yields for *Lolium perenne* L. and *Poa pratensis* L. increased as cutting height increased from 1.23 – 7.25 cm but decreased with increases in nitrogen supply from 1 mM to 10 mM, 4 mM being the tipping point. Below 4 mM, tillering in both species increased for all but the lowest mowing heights and above 4 mM tillers was unchanged or suppressed (Adams et al., 1974). Adams et al. (1974) also reported quantity of roots and depth of rooting is reduced by increases in nitrogen levels causing an increase in shoot growth.

1.5. Drought

Drought is a period that has a shortage of available water in which plant transpiration rates exceeds the rate of water absorb (Beard, 1973). As a result, plants beginning to wilt and desiccation (Beard, 1973). Plants respond to water shortages by escape, avoidance, or tolerance

(Katcher et al., 2008). Drought escape is characterized as a plant that grows quickly during suitable environmental periods and then goes dormant when those resources are not available in sustainable levels (Kramer, 1980; Jones et al., 1981). Some plants can avoid drought by shedding or folding leaves, developing thick cuticles and closing stomata to reduce transpiration (Fry and Huang, 2004). Plant tolerance to drought refers to maintaining high tissue water potential through change in hydraulic conductance while decreasing epidermal conductance, radiation absorption and evaporative surfaces; or, maintaining low tissue water potential where cell turgor is controlled by solutes and increased elasticity or through protoplasmic resistance and desiccation tolerance (Jones et al., 1981).

An important determinant to drought resistance is efficient water uptake which depends on root length and mass, activity and spatial distribution (Huang and Goa, 2000). Hays et al. (1991) evaluated ten bermudagrass [*Cynodon dactylon* (L.) Pers.] genotypes exposed to drought and reported bermudagrasses that had uniformly distributed roots within the soil exhibited superior drought avoidance. Huang and Fry (1998) reported specific root length and root/shoot ratios increased with soil drying for several tall fescue cultivars [*Fustuca arundinacea* (Schreb.)] (‘Mustang,’ ‘MIC19’ and ‘Kentucky-31’). Huang, et al. (1997) also ranked centipedegrass ‘TifBlair’, along with ‘PI 509019’ paspalum, as having the best drought resistance when compared to other warm-season turfgrass species. In general, these authors found deeper rooting at deeper soil depths and root viability allowed greater water uptake for increased drought resistance during periods of water stress.

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Chapter 2. Impact of Preemergence Herbicides on Centipedegrass Rooting and Drought Response in the Mid-Southern United States

2.1. Introduction

Preemergence herbicides (PRE) commonly applied to centipedegrass to reduce weed infestations have been reported to alter rooting of many turfgrass species. Changes in rooting from a PRE application during early spring could affect turfgrass drought tolerance especially later in the growing season when drought conditions typically occur. A study was conducted to examine the impact of PRE on centipedegrass rooting and drought response. Centipedegrass was treated with dithiopyr, pendimethalin, prodiamine, simazine, or indaziflam at manufacturers' labeled rates at two locations in Louisiana. During the 11-wk experiments, roots were harvested at upper (0 to 7.5 cm) and lower (7.5 to 15 cm) soil depths and analyzed for root length (RL), surface area (SA), average diameter (AD), length volume^{-1} (LPV), and root mass (RM). Across all herbicide treatments and soil depths, centipedegrass root parameters for RL, SA, LPV, and RM increased from 2063 cm, 223.6 cm^2, 23.71 cm x 10^6 m^{-3}, and 330.9 mg, respectively, at initiation of experiments to 2272.6 cm, 248.9 cm^2, 26.07 cm x 10^6 m^{-3}, and 434.0 mg at 8 weeks after treatment (WAT). However, PRE did not alter rooting compared to controls with the exception of AD for simazine-treated centipedegrass at 0.397 mm compared to 0.338 and 0.341 mm for prodiamine and indaziflam, respectively. At 11 wks, centipedegrass cores were harvested and subjected to a 28 d dry-down period under greenhouse conditions. All PRE-treated centipedegrass exhibited similar patterns of leaf firing and evapotranspiration compared to controls. Centipedegrass maintained acceptable leaf color for 13 days before complete leaf firing occurred at 20 days. A single application of PRE to mature centipedegrass during early spring did not alter rooting nor affect drought tolerance of centipedegrass compared to controls.

Preemergence herbicides (PRE) are commonly applied in late winter or early spring to home lawns to reduce annual weed infestations (Gomez de Barreda et al., 2013; Johnson and Murphy, 1993; McCarty et al., 1995). Preemergence herbicides provide benefits of extended weed control, minimal leaf phytotoxicity, and prevent visual presence of several weed species within the turfgrass canopy (Johnson and Murphy, 1993). However, some PRE compounds have been reported to negatively alter turfgrass rooting (Fishel and Coats, 1993; Jones et al., 2013; Turgeon et al., 1974) which calls into question their effects on plant stress tolerances.

Effects of PRE on rooting have been well document in scientific literature for many agronomic and horticultural species (Jones et al., 2013; McCarty et al., 1995; Turgeon et al., 1974). Armbruster et al. (1991) reported wheat (*Triticum aestivum* L.) seedlings treated with a 5-ml solution of dithiopyr (2µM) resulted in a cessation of root elongation and a progressive swelling in the zone of root elongation. Vaughn and Vaughan (1988) noted anticytoskeletal herbicides disrupted microtubule formation that resulted in malformation of roots or a thickening of the root often referred to as root clubbing. In a study examining PRE effects on warm-season turfgrass sod production, McCarty et al. (1995) reported pendimethalin and dithiopyr applied at rates of 1.1 or 2.2 kg ha^{-1} and 0.4 or 0.8 kg ha^{-1}, respectively, reduced root biomass by more than 70% for St. Augustinegrass [*Stenotaphrum secundatum* (Walter) Kuntze] grown on sandy soils. Other studies examining PRE effects on warm-season turfgrass species have reported reduced root biomasses, especially near the soil surface, particularly with finer soil textures (Fishel and Coats, 1993; Jones et al., 2013).

Roots serve both important physiological and structural functions involving nutrient and water uptake to anchoring of the plant to the soil (Beard, 1973). Since the root-to-shoot ratio of plants increase with water stress (Turner, 1979), it is reasonable that exposure of roots to compounds such as PRE that could reduce rooting or cause root malformation may limit root growth and reduce overall plant stress tolerance. Several studies have correlated rooting parameters to changes in turfgrass tolerance to drought (Carrow, 1996; Richardson et al., 2008; Quin, et al., 1997). Bonos and Murphy (1999) found increased rooting of Kentucky bluegrass (*Poa pratensis* L.) conferred greater drought survival by comparing stress-tolerant to stress-intolerant cultivars. The authors reported tolerant cultivars had lower soil water content at the lower soil depth of 15 to 30-cm compared to intolerant cultivars. The prevailing theory, across many studies examining rooting effects on drought survival, is that deeper root penetration within the soil allows increased turfgrass access to soil moisture (Qian et al., 1997; Sheffer et al., 1978; Su et al., 2008). This in turn allows the plant to remain turgid and continue transpiration during droughty conditions.

Based on past research examining PRE effects on turfgrass rooting, there remains some question as to the effects PRE have on mature turfgrass roots. If there are any deleterious effects on rooting, one may question if these changes in rooting have any prolonged consequences on turfgrass drought survival. This is particularly relevant for homeowners that do not have irrigation systems and are located in the Mid-Southern United States where summer temperatures often exceed 30 ˚C and water conservation practices are being encouraged. Therefore, the objectives of this study were to determine the impact of commonly applied PRE on mature centipedegrass rooting and their effects on drought tolerance.

2.2. Materials and Methods

Experimental location and setup

Experiments to examine the effects of PRE on turfgrass rooting were conducted on established common centipedegrass [*Eremochloa ophiuroides* (Munro) Hack.] at the Louisiana

State University Agricultural Center Stations located in Baton Rouge, La. (30.409724, -91.101020) and Hammond, La. (30.503195, -90.376127) beginning March 2016. The soils at each location were an Oprairie (Fine-silty, mixed, semiactive, thermic Fragiaquic Glossudalf) silt with a pH 7.1 and 6.6 and 71.9 ppm P and K in Baton Rouge and a Cahaba (Fine-loamy, siliceous, semiactive, thermic Typic Hapludults) fine sandy loam (Web Soil Survey. N.p., n.d. Web. 06 June 2017) with a pH 5.5 and 6.6 and 61.7 ppm P and K in Hammond. No fertilizers or pesticides were applied 6 months prior to initiating experiments.

Preemergence herbicide treatments were arranged in a randomized complete block with three replications at each location. Single PRE applications were applied to 3.3 m^2 (1.8 m X 1.8 m) plots using a pressurized CO_2–backpack with water as the carrier at a spray volume of 46 L ha^{-1}. Preemergence herbicide treatments and application rates were: dithiopyr (S,S-dimethyl 2-(difluoromethyl)-4-4(2-methylpropyl)-6-(trifluoromethyl)-3,5-pyridinedicarbothioate) at 68.89 g a.i. ha^{-1}; pendimethalin (N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine) at 29.7 g a.i. ha^{-1}; prodiamine (2,4-dinitro-N,N- dipropyl-6-(trifluoromethyl)- 1,3-benzenediamin) at 149.1 g a.i. ha^{-1}; simazine (2-chloro-4,6-bis(ethylamino)-s-triazine) at 367.2 g a.i. ha^{-1}; and indaziflam ((N-[(1R,2S)-2,3-dihydro-2,6-dimethyl-1H-inden-1-yl]-6-[(1RS)-1 fluoroethyl]-1,3,5-triazine-2,4-diamine) at 5.2 g a.i. ha^{-1}.

Centipedegrass was maintained at a bench height of 7.5 cm weekly using a mulching rotary mower. Measurements for soil temperature (15 cm) and ratings for turf quality were recorded prior to mowing. Turf quality ratings were based on 0 to 9 scale (0 = death; 5 = minimal acceptable; 9 = ideal quality) following guidelines from the National Turfgrass Evaluation Program (Morris and Shearman, 2017).

Root analysis

Roots were harvested (3.8 cm X 15.2 cm) at upper (0 to 7.5 cm) and lower (7.5 to 15 cm) soil depths from each experimental unit at 0, 3, 5, 8 and 11 weeks after treatment (WAT) in Baton Rouge and at 0, 3, 7 and 11 WAT in Hammond. Leaf tissue was excised and each soil core was placed in individual 2-L plastic pails filled with a 3% (w/v) sodium hexametaphosphate solution and allowed to soak for 3 days. Core segments were washed free of soil and placed in 50 ml specimen containers filled with water and kept at 7 °C until root analyses were conducted.

Roots were scanned at 400 dpi and analyzed for root length (RL) (cm), surface area (SA) (cm^2), average diameter (AD) (mm), and length $volume^{-1}$ (LPV) (cm x 10^6 m3) using WINRhizo Pro (Regent Instruments Inc., Quebec, Canada). Roots were then dried for 72 hrs. at 70 °C and biomass recorded.

Drought tolerance

Plant-soil cores (10.8 cm X 15.2 cm) were harvested from each PRE treatment at 11 WAT at each location. The sides of the cores were immediately wrapped in plastic wrap and foil to prevent moisture loss and light penetration. Cores were then placed in water filled trays (10 cm) for 24 hrs to saturate the soil before being removed and allowed to drain freely. Cores were then placed under greenhouse conditions with at an average high temperature of 34 ˚C with no supplemental irrigation applied to simulate drought conditions. Every 2 to 3 days during the dry-down period leaf firing and water loss, measured as core mass, were recorded for up to 28 days. Leaf firing measurements were based on a scale of 0 to 9 (0 = death; 5 = minimal acceptable; 9 = ideal color).

Experimental statistical analysis

The experimental design was a randomized block design with three replications at each location. For the field portion of the experiments fixed factors included PRE, root harvest depth (0 to 7.6 cm or 7.6 to 15.2 cm), and date of root harvest. In the greenhouse, fixed factors during the dry-down period included PRE and date of measurement. Analyses of all data were conducted using statistical software (SAS Inc., Cary, NC) with repeated measures. Mean separations procedures followed Tukey's method (p-value≤0.05) when fixed factors were significant (p-value≤0.05).

2.3. Results and Discussion

During the experiment, soil temperatures at Burden and Hammond, La increased initially from 21 and 23 °C, respectively, to 28 and 27 °C 11 WAT with total precipitation accumulation of 32 and 24 cm (Table 2.1). Soil temperatures exceeded minimum temperatures of 11.7 to 15 °C and 15.6 to 18.3 °C that have been previously reported for germination of annual grassy weed species crabgrass (*Digitaria* spp.) and goosegrass (*Eleusine indica* (L.) Gaertn.) (Murphy, 2017)

Table 2.1. Environmental conditions during evaluation of preemergence herbicides on centipedegrass in Louisiana in 2016.

2016	Avg. soil temperature	Max air temperature	Accumulated Precipitation
	---˚C---	---˚C---	---cm---
		Baton Rouge, La	
April 16 – April 30	23	27	8.9
May 1 – May 31	24	30	12.6
June 1 – June 15	26	33	10.4
		Hammond, La	
April 22 – April 30	23	29	5.8
May 1 – May 31	23	30	8.2
June 1 – June 30	26	33	6.2
July 1 – July 2	27	36	3.8

and were suitable for warm-season turfgrass growth (Beard, 1973). In addition, precipitation at each location appeared to be sufficient to allow weed seed germination and active centipedegrass growth.

Throughout the 11-wk experiment, no PRE resulted in reduced centipedegrass quality compared to controls (Figure 2.1). This agrees with past experiments that have shown tolerance of several turfgrass species to various PRE. Johnson (1979) reported in a three-year study of atrazine [6-Chloro-N-ethyl-N'-(1-methylethyl)-1,3,5-triazine-2,4-diamine] applied at 2.2 kg ha^{-1} 2 or 3 times per year did not adversely affect established centipedegrass stands; while Turner et al. (1990) found pendimethalin and simazine applied at 1.7 and 2.2 kg ha^{-1}, respectively, were shown to have no phytotoxic effects when applied to a mature stand of centipedegrass.

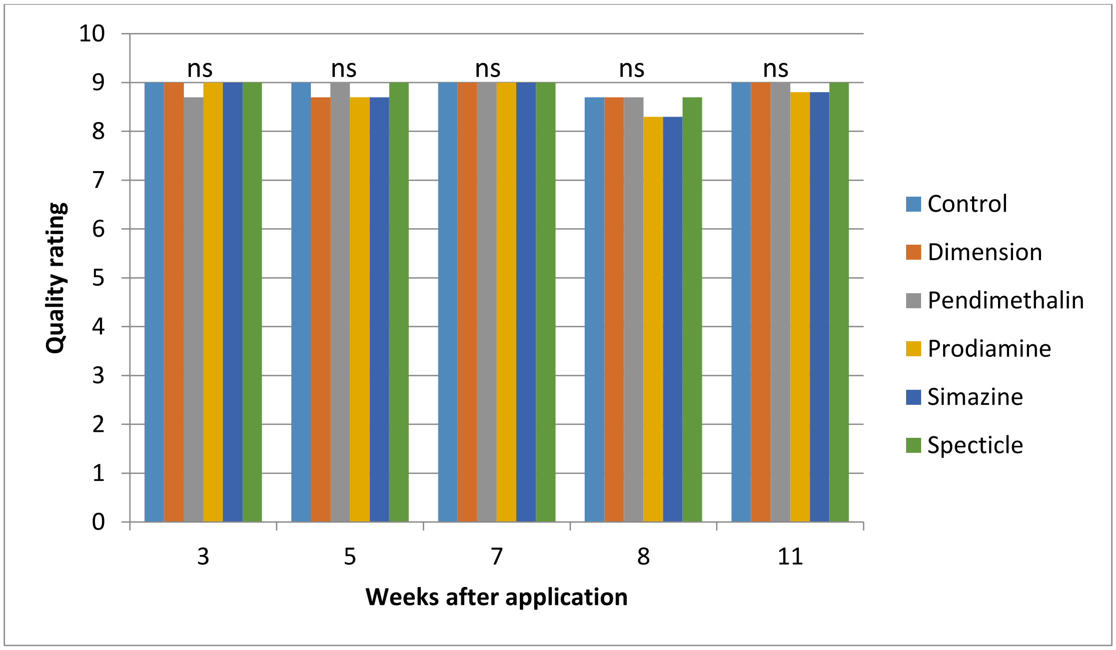

Figure 2.1. Turfgrass quality of centipedegrass treated with preemergence herbicides in Louisiana in 2016.

Deleterious effects of PRE on turfgrass injury appear to be more prevalent for warm-season species growing on coarser textured soils with low organic matter concentrations (Grover, 1966) or when PRE are applied to juvenile plants during establishment (Gomez de Berreda et al., 2013). In this experiment, PRE were applied to mature centipedegrass swards growing in finer textured soils. Therefore, any negative effects of PRE on the turfgrass were most likely ameliorated by the age of the turf in conjunction with the effects of a finer textured soil on PRE activity.

The tolerance of centipedegrass to applied PRE was also mirrored with little to no effect on rooting parameters. Root length, SA, LPV, and RM for treated-centipedegrass were only affected by root harvest date and soil depth but not PRE treatment (Table 2.2). Over time, across all herbicide treatments and soil depths, centipedegrass RL, SA, LPV, and RM increased from 2063.02 cm, 223.59 cm^2, 23.71 cm x 10^6 m^{-3}, and 330.9 mg, respectively, at initiation of experiments to 2272.57 cm, 248.91 cm^2, 26.07 cm x 10^6 m^{-3}, and 434.0 mg at 8 WAT (Table 2.3). For these root parameters, all data was higher in the upper 7.5 cm compared to rooting at the lower soil depth at all root harvest dates (Table 2.4). A pattern of increasing rooting

Table 2.2. Statistical analysis of preemergence herbicide effects on centipedegrass rooting parameters and depth over an 11 week period in Louisiana in 2016.

Fixed Effects	Degrees of freedom	Root length	Surface area	Average diameter	Length volume^{-1}	Root Mass
		-------------------------p-value-------------------------				
Herbicide	5	NS[†]	NS	**	NS	NS
Week	5	**	**	NS	**	***
Herbicide x Week	25	NS	NS	NS	NS	NS
Depth (0-15 cm)	1	***	***	NS	***	***
Herbicide x Depth	5	NS	NS	NS	NS	NS
Week x Depth	5	***	***	*	***	***
Herbicide x Week x Depth	25	NS	NS	NS	NS	NS

† p-value significance is represented at * = < 0.05, ** = < 0.01, *** = < 0.001, NS = Not Significant.

corresponded with changes in increasing temperature. Islam and Hirate (2005) and Bao and Hirata (2006) reported centipedegrass to grow best in tropical and subtropical climates with more rapid growth occurring when summer temperatures exceed 20 ˚C. As the temperature increased over the experimental period centipedegrass vigor and rooting also increased.

The only rooting parameter to be affected by PRE treatments was AD (Tables 2.3 and 2.4). No PRE increased or decreased root AD across the experimental period compared to controls. Differences in AD only occurred between roots treated with simazine at 0.397 mm compared to 0.338 and 0.341mm for prodiamine- and indaziflam-treated centipedegrass, respectively. However, the effects of PRE treatments on root swelling may be understated for certain PRE due to their transient effect on rooting. For example, the differences in AD from PRE at 3 WAT suggest root swelling may have been present. Dithiopyr, pendimethalin, and simazine resulted in increased AD of 11, 29, 47% compared to controls while prodiamine and idaziflam resulted in -2.2 and 2% differences in AD from controls. This agrees with past studies such as Armbruster et al. (1991) and Brabham et al. (1989 and 2014) who reported root swelling in poa (*Poa annua* L.) and wheat [*Triticum aestivum* L.] cv. ‘Chris’ within hours after application of PRE. Effects on turfgrass rooting treated with PRE were found to be short-lived and dissipated within weeks after application as has been reported for other turfgrass species treated with PRE (Landschoot et al., 1993).

The lack of effect of PRE on centipedegrass rooting appears to be incongruent to many other studies evaluating PRE effects on warm-season turfgrasses (Gomez de Barreda et al., 2013; Jones et al., 2013; McCarty et al., 1995; Turner et al., 1990). This is most likely a result of environmental conditions and experimental methods employed. Many studies examining PRE

Table 2.3. Preemergence herbicide effects on centipedegrass rooting to a depth of 15 cm over 11 weeks in Louisiana in 2016.

Herbicide Treatment	Root length	Surface area	Average diameter	Length volume^{-1}	Root mass
	--------cm-------	------cm^{2}-------	--------mm--------	---cm x 10^{6} m^{-2}--	-------mg------
Control	1175.8 A[†]	127.1 A	0.357 AB	13.5 A	208.8 A
Dithiopyr	1041.7 A	114.3 A	0.359 AB	12.0 A	193.0 A
Indaziflam	987.9 A	106.2 A	0.341 B	11.4 A	191.5 A
Pendimethalin	1046.4 A	114.5 A	0.358 AB	12.0 A	190.1 A
Prodiamine	1053.4 A	113.4 A	0.338 B	12.1 A	188.4 A
Simazine	995.4 A	116.9 A	0.397 A	11.5 A	195.8 A

† Values followed by different letters are significantly different (α = 0.05) according to Tukey's mean separation procedure.

Table 2.4. Impact of preemergence herbicide application on centipedegrass rooting characteristics at two soil depths (0 to 7.5 cm and 7.5 to 15 cm) in 2016.

Weeks	Root Length		Surface Area		Length Volume^{-1}		Root Mass	
	Upper Soil Depth	Lower Soil Depth	Upper Soil Depth	Lower Soil Depth	Upper Soil Depth	Lower Soil Depth	Upper Soil Depth	Lower Soil Depth
	------------------cm---------------		---------------cm^{2}-----------		------cm x 10^{6} m^{-2}-----		-----------------mg---------------	
0	1320.9 C[†]	742.1 D	148.4 C	75.2 D	15.2 C	8.5 D	226.6 D	104.3 E
3	1310.4 C	576.0 D	148.6 C	62.6 D	15.1 C	6.6 D	279.0 BD	90.7 E
5	1343.5 BC	558.0 D	147.0 D	60.2 C	15.4 BC	6.4 D	277.6 CD	98.8 E
7	1678.7 AB	663.3 C	194.3 D	70.4 A	19.3 AB	7.6 D	342.9 AC	78.2 E
8	1700.4 A	572.1 D	186.2 AB	62.7 D	19.5 A	6.6 D	343.5 AB	91.4 E
11	1459.8 ABC	676.6 D	158.6 BC	70.5 D	16.8 ABC	7.8 D	303.3 ABC	98.9 E

† Values followed by different letters within each root parameter are significantly different (α = 0.05) according to Tukey's mean separation procedure.

effects on warm-season turfgrasses have been conducted on coarser textured soils (Jones et al., 2013a; Jones et al., 2013b; McCarty et al., 1995). For example, Jones et al. (2013) reported bermudagrass [*C. dactylon* (L.) Pers. X *C. transvaalensis* Burtt-Davey] cv. 'Tifway' growing in sand had greater susceptibility to indaziflam not only as the application rate increased from 35 to 52.5 g ai ha^{-1} but also as organic matter concentrations declined from 0.012 to 0.00 kg kg^{-1} for sand amended with reed peat moss. Binding of a pesticide can alter a pesticide's availability and efficacy and thus turfgrass tolerance to PRE. The effect of organic matter and finer textured soils can also limit PRE movement within the soil profile (Grover, 1966; Jones et al., 2013a) which would directly affect root-herbicide interactions especially at lower soil depths where root meristematic tissue may be more prevalent. In other agronomic and horticultural species root swelling or clubbing is associated at root tips that have contact with compounds including indaziflam, dinitroanilines like pendimethalin and prodiamine, and trifluralin which inhibit cellulose biosynthesis, cell division and cell mitosis, respectively (Ambruster et al., 1991; Appleby et al., 1989; Bayer et al., 1967; Brabham et al., 2014).

Another reason for lack of differences in rooting in this experiment compared to past studies may also be a function of turf age. As stated previously, these experiments were conducted on mature centipedegrass swards growing on a finer textured soil. Mature turfs typically have increased organic matter within the upper soil profile. Grover (1966) found that heavy clay amended with peat required an additional 0.16 ppm simazine for each 2.2 to 2.6% increase in organic matter to reduce oat [Avena sativa (L.) var. Rodney] growth by 50%. In many studies evaluating PRE effects on turfgrass rooting, plugs, sprigs, ribbons, or sod were evaluated on treated soils (Fishel and Coats, 1993; Gomez de Barreda et al., 2013; McCarty et al., 1995). The deleterious effects of PRE reported for immature plants growing in coarse soil may not be the same for mature turfgrasses growing in fine texture soils especially under field conditions. Impacts of PRE on rooting may be lessened because of more developed centipedegrass root systems at the time of application that could also affect PRE interaction at the root meristems.

Due to the similarity in centipedegrass responses to PRE, centipedegrass exhibited similar declining patterns in leaf firing and evapotranspiration during the 28-day dry-down period of the experiments (Tables 2.5 and 2.6). There were no differences in leaf firing or water loss between individual PRE-treated centipedegrass and controls (Figures 2.2 and 2.3). In general, centipedegrass exhibited ratings above 5 for 13 days before declining to leaf firing ratings of ≤1at 20 days. The only differences to occur in overall drought tolerance was between prodiamine-treated centipedegrass that exhibited slower leaf firing compared to dithiopyr and pendimethalin-treated centipedegrass. In conjunction with changes in leaf firing, water loss in the form of evapotranspiration declined from 2368.8 to 1732.0 g over the 28 days with no differences occurring among PRE treatments and controls.

Table 2.5. Statistical analysis of preemergence herbicide effects on centipedegrass drought response during a 28-day drought simulation in 2016.

Fixed Effects	Degrees Of Freedom	Leaf Firing	Evapotranspiration
	-------------------------p-value	-------------------------	
Treatment (TRT)	5	*	NS
Days after Treatment (DAT)	16	***	***
TRT x DAT	80	NS	NS

† p-value significance is represented at * = < 0.05, ** = < 0.01, *** = < 0.001, NS = Not Significant.

Table 2.6. Impact of preemergence herbicide application on centipedegrass rooting average diameter at two soil depths (0 to 7.5 cm and 7.5 to 15 cm) in 2016.

Weeks	Average Diameter			
	Upper Soil Depth		Lower Soil Depth	
	------------------------------------mm		-------------------------------------	
0	0.360	AB	0.326	B
3	0.365	AB	0.412	A
5	0.356	AB	0.330	AB
7	0.365	AB	0.393	AB
8	0.362	AB	0.334	AB
11	0.350	AB	0.348	AB

† Values followed by different letters are significantly different (α = 0.05) according to Tukey’s mean separation procedure.

The similarity in centipedegrass response to drought simulation across PRE treatments is most likely the result of similarities in centipedegrass rooting. If centipedegrass rooting is unaffected by PRE at 11 WAT, a period during the growing season when increasing temperatures intensify would be expected to exacerbate drought conditions, then evapotranspiration would be expected to be unaffected. In comparison, factors or compounds that limit root proliferation and extension would be expected to reduce turfgrass drought survival. Plants that can increase rooting gain greater access to soil moisture to maintain leaf transpiration. Bonos et al. (2004) correlated deeper rooting of tall fescue (*Festuca arundinacea* Schreb.) led to greater drought tolerance. Therefore, the lack of differences in rooting of PRE-treated centipedegrass compared to controls indicate any transient alterations in rooting from a single PRE did not have lasting detrimental effects on centipedegrass drought tolerance. It is

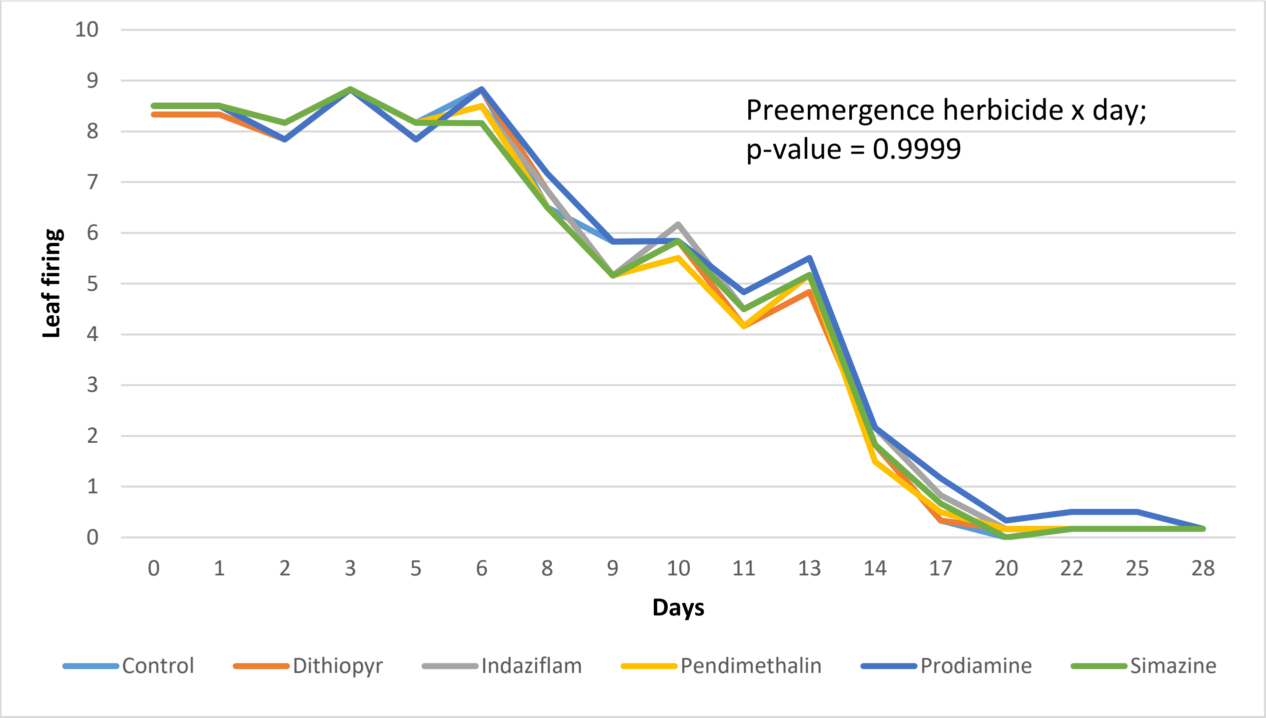

Figure 2.2. Leaf firing during a 28-day drought simulation on centipedegrass treated with preemergence herbicides in 2016.

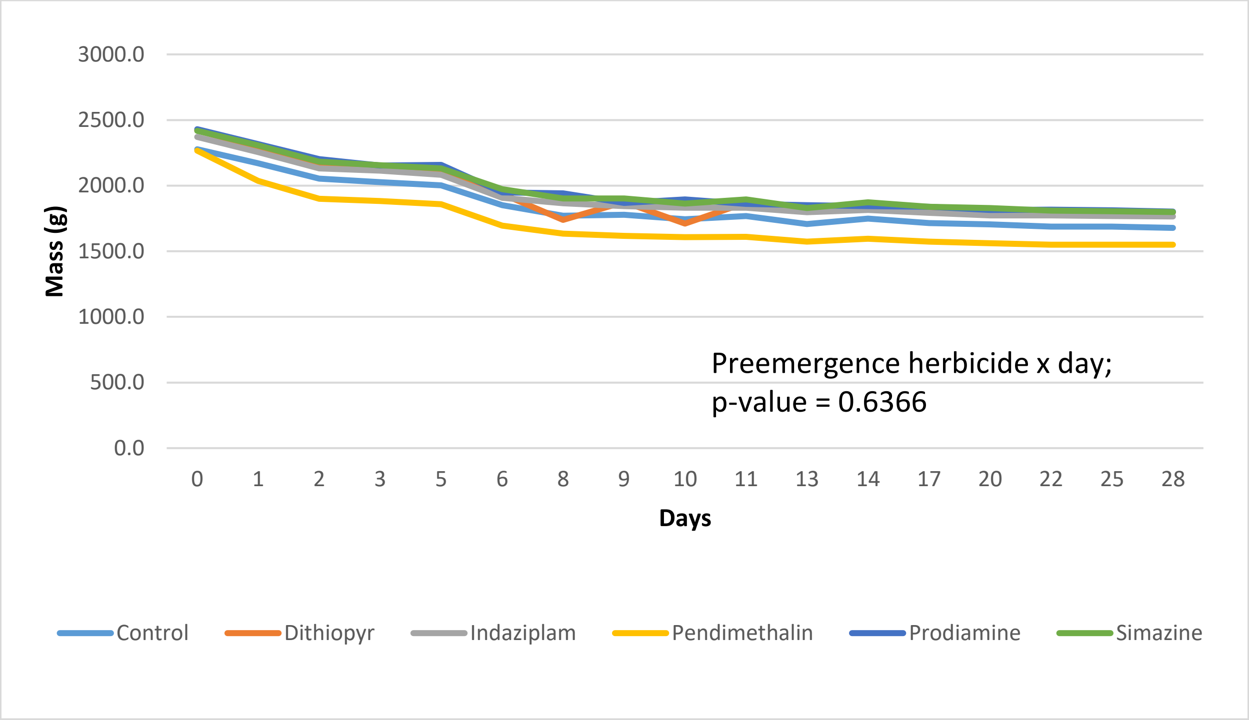

Figure 2.3. Evapotranspiration during a 28-day drought simulation on centipedegrass treated with preemergence herbicides in 2016.

important to note that future studies need to be conducted to examine repeated PRE applications within a year as well as PRE applied over the course of years to fully characterize PRE effects on centipedegrass rooting and drought survival.

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Chapter 3. Increasing Mowing Height and Nitrogen Fertility did not Extend Centipedegrass Drought Survival During Drought Simulation

3.1. Introduction

Mowing and fertilization are cultural practices commonly performed on centipedegrass to improve overall turf quality. It is posited that increasing mowing height and application of fertilizers can lead to greater turfgrass rooting and thus drought survival. To examine the effects of mowing height and fertility on centipedegrass rooting and drought tolerance, a study was conducted at two locations in Louisiana. Centipedegrass was maintained at one of four mowing heights (2.5, 5, 7.5 and 10 cm) and subjected to fertilization or no fertilization. During the 29-wk experiments, roots were harvested at upper (0 to 7.5 cm) and lower (7.5 to 15 cm) soil depths and analyzed for root length (RL), surface area (SA), average diameter (AD), length volume^{-1} (LPV), and root mass (RM). In July, centipedegrass was subjected to 33-day drought simulation under greenhouse conditions. All centipedegrass exhibited a pattern of increased leaf firing over the drought simulation with unfertilized centipedegrass maintaining acceptable leaf color ($\geq$5) for 19 days at 5.9 compared to 4.8 when fertilized. Centipedegrass rooting parameters across all mowing heights and soil depths for initial RL, SA, LPV, and RM measurements were 2170.8 cm, 223.6 cm^2, 26.2 cm x 10^6 m^{-3}, 331.1 mg, respectively, compared to declines to 1772.5 cm, 173.1 cm^2, 20.4 cm x 10^6 m^{-3}, 260.4 mg at 20 weeks before increasing to 2293.6 cm, 233.8 cm^2, 26.4 cm x 10^6 m^{-3}, 334.7 mg at 29 weeks. The pattern of declining centipedegrass rooting from spring into summer followed by increased rooting in fall in conjunction with the lack of changes in rooting from alterations in cultural practices indicate soil temperature may be a significant factor in centipedegrass rooting.

Centipedegrass is a warm-season turfgrass that is commonly grown in many home and commercial landscapes in the Southern United States. Centipedegrass is a slow, prostrate growing turfgrass species that requires low to moderate levels of fertility and possesses excellent heat and moderate shade and drought tolerances (Beard, 1973; Duble, 1989; Islam and Hirata, 2005). Although centipedegrass is often described as a turfgrass species that can tolerate reduced management compared to other warm-season turfgrasses, centipedegrass grown in home and commercial landscapes must be managed to maintain aesthetic quality throughout the growing season.

Two primary cultural practices performed by many homeowners and turf practitioners include N fertilization and mowing. Nitrogen, which constitutes 3 to 6% of turfgrass dry matter, is a vital component of chlorophyll, amino acids and proteins, nucleic acids, and enzymes that affects shoot growth, root growth, shoot density, leaf color, disease resistance, tolerance to heat, cold and drought stresses, recuperative potential and competitiveness within a turfgrass sward (Beard, 1973). Mowing at the recommended height for a specific turfgrass species is an important cultural practice because it stimulates aerial shoot growth; increases shoot density, root development and wear tolerance; decreases weed encroachment; and improves overall turf quality (Duble, 1989; R. Emmons, 2008; Fry and Huang, 2004; Turgeon, 2005). However, improper N fertilization of centipedegrass has been shown to hinder growth and thus overall turfgrass vigor (Toler et al., 2007); while improper mowing can cause a cessation of root growth, reduction in carbohydrate production and storage, create ports of entry for plant pathogens, increase water loss from cut leaf ends and reduce water absorption by the roots (Turgeon, 2005).

In the Southern United States, centipedegrass is susceptible to periodic drought during the summer months when temperatures often exceed 32 ˚C. Because many home and commercial lawns do not have irrigation, turfgrass managers must rely on implementing primary cultural practices to increase centipedegrass vigor. Changes in N fertility and mowing heights have specifically been correlated to changes in root and shoot growth for several turfgrass species and thus turfgrass tolerances to environmental stresses such as drought (Fry and Huang, 2004; Harrison, 1931). In experiments conducted by Adams et al. (1974), it was shown that while root yields increased with cutting height and decreased with increase in nitrogen availability, top growth in turfgrass took precedence over root growth evidenced as an increase in nitrogen supply led to greater verdure and less phothosynthate being translocated to roots for reduced root growth. To compensate for the reduction in carbohydrate production, leaf chlorophyll content can increase in turfgrasses (Fry and Huang, 2004). More specific to mowing height, Tucker et al. (2006) showed root length density increased 10% when mowing heights for the Bermudagrass cultivar 'TifEagle' [*Cynodon dactylon* (L.) Peers. X *C. transvaalensis* Butt-Davy] increased from 3.2 to 4.0 and 4.8 mm; while Liu and Bengru, (2002) reported increasing mowing height from 3 to 9 cm increased total root length for two culivars of creeping bentgrass (*Agrostis palustris* Huds.) 'Crenshaw' and 'Penncross'. Increasing mowing height can allow for greater photosynthetic capacity through increased leaf surface area. Greater photosynthetic capacity provides energy that can be funneled into root growth. Therefore, no more than 40% leaf blade removal is recommended because removal above 40% of turfgrass foliage can halt root growth up to several days (Crider,1954).

While turfgrass root systems are generally shallow relative to many other grasses and weed species (Kaufmann, 1994), turfgrass roots function to anchor the plant, stabilize soil, increase stress tolerance and store energy. During droughty conditions turfgrasses that have deeper root penetration gain access to greater soil moisture to maintain transpiration for longer periods compared to shallower rooted turfgrass species and cultivars (Emmons, 2008). Bonos and Murphy (1999) reported greater drought tolerance of Kentucky bluegrass (*Poa pratensis* L.)

was more evident for cultivars that extracted water at 15 to 30 cm soil depths through deeper root penetration. Several environmental are known to influence root growth including soil temperature, moisture, compaction (Tucker et al, 2006), as well as, cultural practices such as mowing height and fertilization.

Increasing rooting is an extremely desirable drought tolerance mechanism that can enhance water uptake and allowing turf to better utilize available water in the soil to prolong the need for irrigation (Richardson, et al, 2008) or duration until natural precipitation occurs. In a subtropical region such as Louisiana where annual precipitation can exceed 152 cm (Grymes, 2011), weeks can go by in the hot summer months without rainfall, this study attempts to discover to what extent mowing height and N-fertilization alter rooting and to what extent do these practices impact drought tolerance in unirrigated centipedegrass turf.

3.2. Materials and Methods

Experimental location and setup

Experiments to examine the effects of mowing height and N fertilization on turfgrass rooting were conducted on established common centipedegrass [*Eremochloa ophiuroides* (Munro) Hack.] at the Louisiana State University Agricultural Center Stations located in Baton Rouge, La. (30.409724, -91.101020) and Hammond, La. (30.503195, -90.376127) beginning April 2016. The soils at each location were an Oprairie (Fine-silty, mixed, semi-active, thermic Fragiaquic Glossudalf) silt with a pH 6.7 and 9.9 and 83.9 mg L^{-1} P and K in Baton Rouge and a Cahaba (Fine-loamy, siliceous, semi-active, thermic Typic Hapludults) fine sandy loam with a pH 5.5 and 2.5 and 63.7 mg L^{-1} P and K in Hammond (Web Soil Survey. N.p., n.d. Web. 06 June 2017). No fertilizers or pesticides were applied 6 months prior to initiating experiments. No supplemental irrigation was applied during the experiments but total rainfall was 90.2 cm in Baton Rouge and 39.7 cm in Hammond.

Mowing height treatments were arranged in a split-plot with three replications at each location. Mowing was performed weekly at bench heights of 2.5, 5., 7.5 and 10 cm using a mulching rotary mower to centipedegrass with areas of 5.6 m^2 (3.05 X 1.83 m). Within each centipedegrass mowing treatment, a complete fertilizer (13-13-13, Shell Beach Inc., Many, LA), with nutrients derived from diammonium phosphate, muriate of potash and urea, was applied to one half of the centipedegrass at 48.8 kg ha^{-1} on 2 April, 2 July, and 15 September. Prior to weekly mowing, measurements for soil temperature (0 to 15 cm) and canopy height were recorded.

Root analysis

Root-soil cores (3.8 cm X 15.2 cm) were harvested from each experimental unit 0, 5, 8 11, 14, 20, 24 and 29 weeks after treatment (WAT) in Baton Rouge and at 0, 5, 8, 11, 15, 20, 25 and 29 WAT in Hammond. Root-soil cores were divided into upper (0 to 7.5 cm) and lower (7.5 to 15 cm) segments. Each core was placed in individual 2-L containers filled with a 3% (w/v) sodium hexametaphosphate solution and allowed to soak for 3 days. Roots were then washed free of soil and placed in 50-ml containers filled with water. Root samples were stored at 7 °C until root analyses were conducted.

Roots were scanned at 400 dpi and analyzed for total root length (RL; cm), total surface area (SA, cm^2), average diameter (AD; mm), length volume-1(LPV; cm x 10^6 m^{-3}) using the WINRhizo Pro (Regent Instruments Inc., Quebec, Canada). Once analyzed, roots were dried for 72 hrs at 70 °C and root mass (RM; mg) recorded.

Drought tolerance

Plant-soil cores (10.8 cm X 15.2 cm) were harvested from each treatment at 11 WAT at each location. The sides of the cores were immediately wrapped in plastic wrap and foil to prevent moisture loss and light penetration. Cores were then placed in water filled trays (10 cm) for 24 hours to saturate the soil before being removed and allowed to drain freely. Cores were then placed under greenhouse conditions with an average temperature of 31.8 ˚C and no supplemental irrigation applied to simulate drought. Every 2 to 3 days during the dry-down period leaf firing was recorded for 33 days. Leaf firing measurements were based on a scale of 0 to 9 (0 = death; 5 = minimal acceptable; 9 = ideal leaf color).

Experimental statistical analysis

The experimental design was a split-plot with three replications at each location. Mowing heights were the main plots and fertility were subplots. Fixed factors included mowing height, fertilizer application, root-core segment depth (0 to 7.5 cm or 7.5 to 15 cm), and date of measurement. For the drought simulation experiments, centipedegrass response was analyzed for the fixed effects of mowing height, fertilizer application, and time. Analysis for all data were analyzed using statistical software (SAS Inc., Cary, NC) with mean separations following Tukey's method ($p\text{-value} \leq 0.05$) when fixed factors were significant ($p\text{-value} \leq 0.05$).

3.3. Results and Discussion

Differences in centipedegrass response during drought simulations initiated July 2016 were observed between N fertility treatments but not mowing heights (Table 3.1). All centipedegrass exhibited a pattern of increased leaf firing over the 36-day drought simulation with unfertilized centipedegrass maintaining acceptable leaf color (≥5) for 19 days at 5.9 compared to 4.8 when fertilized (Figure 3.1). Centipedegrass is considered a low N requiring turfgrass species that has been reported to have slowed growth with excessive N applications (Fry and Huang, 2004). However, prior to initiating drought simulation centipedegrass had increased sward density at the lowest mowing height and increased N fertility, a typical response

Table 3.1. Statistical analysis of turfgrass density and leaf firing for centipedegrass maintained at various mowing heights and fertility.

MHF DT Fixed Effects	Degree Of Freedom	Turfgrass Density	Leaf Firing
		---------------------p-value	-----------------
Mowing Height (MH)	3	***	NS
Fertilization (FERT)	1	NS	**
MH x FERT	3	**	NS
Days after Treatment (DAT)	18	Na	***
MH x DAT	54	Na	NS
FERT x DAT	18	Na	**
MH x FERT x DAT	54	Na	NS

† p-value significance is represented at * = < 0.05, ** = < 0.01, *** = < 0.001, NS = Not Significant.

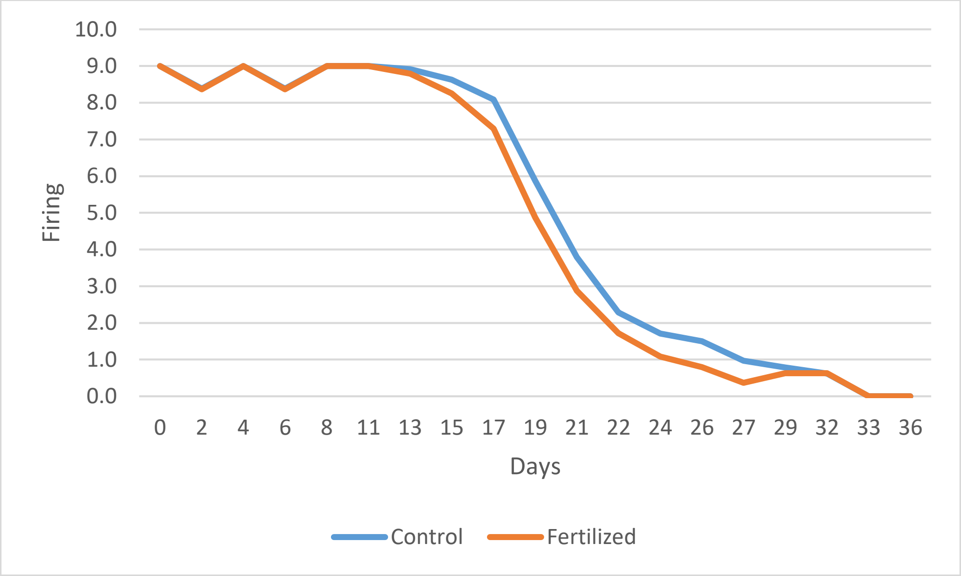

Figure 3.1. Drought response of centipedegrass maintained at different mowing heights (2.5, 5, 7.5, 10 cm) and fertility under a 36-day drought simulation.

of many turfgrass species to changes in mowing and fertility practices (Adams et al., 1974) (Figure 3.2). As a result, increasing shoot tissue can lead to increased transpiration (Fry and Huang, 2004) that can deplete soil moisture faster compared to unfertilized centipedegrass. However, the more interesting response by centipedegrass during the drought simulation was the lack of increased drought tolerance as mowing height increased from recommendations of 2.5 and 5 cm to 7.5 and 10 cm. Many studies examining turfgrass drought tolerance have reported a relationship of increasing mowing height to greater rooting (Harrison, 1931; Emmons, 2008). A proliferation in turfgrass rooting can increase access to greater soil water reserves at deeper soil depths to maintain turfgrass turgor and growth during droughty conditions (Fry and Huang, 2004).

During the 29-wk experiments, centipedegrass rooting changed over time but was not affected by mowing or fertilizer treatments for all rooting parameters (Tables 3.2 - 3.3). In fact, for many rooting parameters, centipedegrass exhibited a pattern of decreasing rooting of 18.3 to 22.6 % from spring into summer before rooting increased between 28.5 and 35.1 % from summer into fall (Table 3.4). More specifically, centipedegrass rooting parameters across all

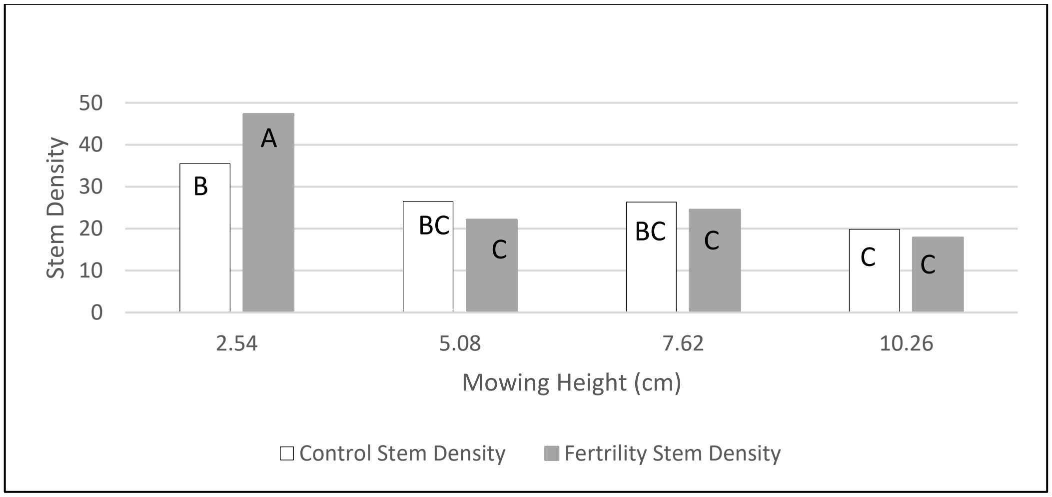

Figure 3.2. Centipedegrass canopy density at different mowing heights and N fertility in July 2016.

Table 3.2. Statistical significance of the fixed effects of mowing height and N fertility on centipedegrass rooting depth during a 29-week growing season in 2016.

Fixed Effects	Degrees of Freedom	Root Length	Surface Area	Average Diameter	Length Volume^{-1}	Root Mass
		----cm----	----cm^2---	----mm----	cm x 10^6 m^{-3}	--mg--
		-------------------------------p-value-------------------------------				
Mowing Height (MH)	3	NS[†]	NS	NS	NS	NS
Fertility (F)	1	NS	NS	NS	NS	NS
MH x F	3	NS	NS	NS	NS	NS
Week (Wk)	11	***	***	*	***	***
MH x Wk	33	NS	NS	NS	NS	NS
F x Wk	11	NS	NS	NS	NS	NS
MH x F x Wk	33	NS	NS	NS	NS	NS
Depth (D)	1	***	***	NS	***	***
MH x D	3	NS	NS	NS	NS	NS
F x D	1	NS	NS	NS	NS	NS
MH x F x D	3	NS	NS	NS	NS	NS
Wk x D	11	***	***	***	***	***
MH x Wk x D	33	NS	NS	NS	NS	NS
F x Wk x D	11	NS	NS	NS	NS	NS
MH x F x Wk x D	33	NS	NS	NS	NS	NS

[†] p-value significance is represented at * = < 0.05, ** = < 0.01, *** = < 0.001, NS = Not Significant.

mowing heights and soil depths for initial RL, SA, LPV, and RM measurements were 2170.8 cm, 223.6 cm^2, 26.2 cm x 10^6 m^{-3}, 331.1 mg, respectively, compared to declines to 1772.5 cm, 173.1 cm^2, 20.4 cm x 10^6 m^{-3}, 260.4 mg at 20 weeks before increasing to 2293.6 cm, 233.8 cm^2, 26.4 cm x 10^6 m^{-3}, 334.7 mg at 29 weeks. Centipedegrass rooting was higher in the upper 7.5 cm of soil compared to rooting at the lower soil depth; and centipedegrass rooting with regard to average root diameter was generally similar at each sampling depth with a range of 0.305 to 0.353 mm (Table 3.5).

The failure to increase centipedegrass rooting through N fertilization and higher mowing heights, especially during late spring and summer when environmental conditions are considered suitable for centipedegrass growth (Islam and Hirate, 2005; Bao and Hirata, 2006), does not align with past research examining these primary cultural practices on turfgrass rooting and

Table 3.3. Effects of mowing height and N fertility on centipedegrass rooting during the growing months of April to November 2016. Data include two locations in Louisiana (Baton Rouge and Hammond).

Mowing Height	Fertilization	Length		Surface Area		Average Diameter		Length Volume $^{-1}$		Root Mass	
--cm--	-kg N ha^{-1}--	-----cm-----		-----cm^2-----		-----mm-----		---cm x 10^6 m^{-3}--		-----mg-----	
2.5	0	977.5	A†	98.6	A	0.324	A	11.2	A	156.5	A
2.5	48.8	900.0	A	92.2	A	0.338	A	10.3	A	138.0	A
5	0	958.4	A	100.4	A	0.340	A	11.0	A	160.0	A
5	48.8	1003.7	A	102.1	A	0.331	A	11.5	A	158.0	A
7.5	0	1060.1	A	104.1	A	0.314	A	12.4	A	162.6	A
7.5	48.8	1031.5	A	103.4	A	0.318	A	12.1	A	157.4	A
10	0	1043.5	A	104.5	A	0.317	A	12.0	A	160.0	A
10	48.8	960.1	A	99.1	A	0.331	A	11.0	A	150.0	A

† Values followed by different letters within a column are significantly different ($\alpha = 0.05$) according to Tukey's mean separation procedure.

drought. For example, increasing the mowing height from 3 to 9 cm resulted in higher total root length for two cultivars of creeping bentgrass (*Agrostis palustris* Huds.) 'Crenshaw' and 'Penncross' (Liu and Huang, 2002); while Tucker et al. (2006) reported increasing the mowing height ≥4 cm and applying N fertility ≥24 kg N ha^{-1} wk^{-1} increased rooting in terms of root length density and surface area for bermudagrass [*Cynodon dactylon* (L.) Pers. x *C. transvaalensis* Burt-Davy] cv.'Tifeagle.' Therefore, the decline in centipedegrass rooting and lack of increased drought tolerance at higher mowing heights and increased N fertility within this study indicate other factors must be considered.

Primary cultural practices should directly affect centipedegrass rooting through changes in centipedegrass shoot growth. Canopy height measured prior to mowing exhibited a pattern of increased vertical growth for centipedegrass mowed at 5, 10, and 15 cm during spring into summer and to a lesser extent for centipedegrass maintained at 2.5 cm (Figure 3.2). In addition,

Table 3.4. Changes in centipedegrass rooting averaged across four mowing heights (2.5, 5, 7.5, and 10 cm) and two fertility levels (0 and 48.8 kg N ha^{-1}) during a 29-week growing season in 2016.

Weeks	Root Length		Surface Area		Root Mass		Length Volume^{-1}	
	Upper Soil Depth	Lower Soil Depth	Upper Soil Depth	Lower Soil Depth	Upper Soil Depth	Lower Soil Depth	Upper Soil Depth	Lower Soil Depth
	----------------------cm-------------------		----------------------cm^2-------------------		------------------mg-------------------		----------cm x 10^6 m^{-3}---------	
0	1365.5 BCD[†]	805.3 EF	147.7 AB	75.9 DE	233.9 ABCD[†]	97.2 E	15.7 BCD	10.5 EFG
3	1195.8 CD	651.1 FG	122.6 BC	65.8 EF	210.3 BCD	86.6 E	13.9 BCDE	7.6 GH
5	1576.4 AB	669.1 FG	166.0 A	64.3 EF	291.5 A	81.2 E	18.0 AB	7.6 GH
7	1336.2 BCD	744.0 FG	138.6 ABC	77.1 DEF	239.8 ABCD	93.2 E	15.5 ABCD	8.7 FGH
8	1489.9 ABC	529.0 FG	154.6 AB	50.8 EF	282.7 AB	69.3 E	17.0 ABC	6.0 H
11	1204.5 CD	675.7 FG	123.9 BC	67.2 EF	231.1 BCD	82.1 E	13.9 CD	7.8 GH
14	1328.1 BCD	416.6 G	136.9 ABC	39.9 F	266.9 ABC	56.2 E	15.2 BCD	4.7 H
15	1151.8 CD	622.7 FG	112.0 BC	62.7 EF	193.8 D	75.1 E	13.4 CDE	7.3 GH
20	1239.7 CD	532.8 G	121.5 BC	51.6 EF	187.1 D	73.3 E	14.3 CD	6.1 H
24	1469.4 ABC	674.6 FG	152.0 AB	61.7 EF	213.7 CD	74.9 E	16.8 ABCD	7.6 GH
25	1090.7 DE	741.2 FG	107.2 CD	71.9 DEF	179.6 D	73.0 E	12.7 DEF	8.6 GH
29	1653.8 A	639.8 FG	170.1 A	63.7 EF	259.7 ABC	75.0 E	19.0 A	7.4 H

Values followed by different letters within each root parameter are significantly different (α = 0.05) according to Tukey's mean separation procedure.

Table 3.5. Average root diameters of centipedegrass across four mowing heights (2.5, 5, 7.5, and 10 cm) and two fertility levels (0 and 48.8 kg N ha^{-1}) during a 29-week growing season in 2016.

Weeks	Average Root Diameter			
	Upper Soil Depth		Lower Soil Depth	
	---------------------------mm---------------------------------			
0	0.342	A[†]	0.304	B
3	0.327	AB	0.338	AB
5	0.346	AB	0.315	AB
7	0.324	AB	0.353	A
8	0.342	AB	0.314	AB
11	0.329	AB	0.324	AB
14	0.340	AB	0.311	AB
15	0.328	AB	0.340	AB
20	0.314	AB	0.319	AB
24	0.340	AB	0.304	AB
25	0.305	AB	0.312	AB
29	0.328	AB	0.339	AB

[†] Values followed by different letters are significantly different (α = 0.05) according to Tukey's mean separation procedure.

application of N showed increased shoot growth particularly with centipedegrass maintained at 7.5 and 10 cm. Based on previous research, it would have been expected that higher canopy heights, from turfgrass leaf extension and increased density, would result in higher photosynthetic capacity of the turfgrass sward that would allow carbohydrates to be funneled downward for greater rooting (Liu and Huang, 2002). However, in these experiments the interaction of N fertility and mowing may have counteracted one another to limit centipedegrass root growth especially during summer. Preference of shoot growth over root growth can occur when N is applied (Adams et al., 1974); while removal of > 40% leaf tissue has been reported to negatively affect root growth and development for a period of at least six days (Crider, 1955). Potential stress from excess tissue removal may be ameliorated through more frequent mowing but would negate the benefits of growing centipedegrass as a reduced input turfgrass.

The lack of response of centipedegrass rooting to increased N fertility induced shoot growth may be have been affected by excessive leaf removal through mowing (Figure 3.3); however, unfertilized centipedegrass at 7.5 and 10 cm did not result in increased rooting compared to centipedegrass maintained at corresponding heights nor unfertilized centipedegrass maintained at 2.5 and 5 cm. Therefore, turfgrass stress from defoliation cannot by itself explain the lack of increased rooting expected for centipedegrass maintained at higher mowing heights.

A factor that may be affecting centipedegrass rooting is soil temperature. Beard (2017) reported soil temperatures between 16 and 26 °C at a soil depth of 10 cm is optimal for warm-season turfgrass root growth. In these experiments, soil temperature was measured to 15 cm because root sampling was performed to that depth (Table 3.6). Soil temperature increased from 23 °C in April and May to $\geq$ 27 °C during July, August, and September in both locations before declining to optimal temperature ranges for root growth in October. The pattern in soil temperature over the growing season corresponded to the pattern exhibited by centipedegrass rooting measured as RL, SA, LPV, and RM over the 29 weeks (Table 3.6). Centipedegrass root dieback appears to have exceeded the rate of root regeneration at the higher soil temperatures.

High soil temperatures relative to air temperature changes have been shown to be affect growth of several plant species (Kasper and Bland, 1992). In one study, Xu and Huang (2000) reported temperature in the root zone affected turfgrass root growth and overall plant stress compared to air temperature for air and soil temperature combinations from 20 to 35 C. Temperature induced changes in root growth would be expected to affect water and nutrient uptake, drought tolerance, and overwintering survival (Beard, 1973). Other factors such as soil texture can affect soil temperature (Abu-Hamdeh and Reed, 2000) with coarser textured soils expected to have greater temperature fluctuations. Therefore, past research examining turfgrass

2.5 cm

5 cm

7.5 cm

10 cm

Figure 3.3. Centipedegrass canopy height prior to mowing for four mowing heights (2.5, 5, 7.5, and 10 cm) and two fertility levels (0 and 48.8 kg N ha^{-1}) during a 29-week growing season in 2016. The solid line in each graph represents >40% reduction in canopy height per mowing height regimen.

Table 3.6. Average air and soil temperatures for centipedegrass

Date (2016)	Ave SOIL TEMP ˚C	Ave Max Air Temp ˚C	Ave SOIL TEMP ˚C	Ave Max Air Temp ˚C
	Baton Rouge, LA		Hammond, LA	
Apr 2 – Apr 30	23	26	23	29
May 1 – May 31	23	30	23	30
June 1 – June 30	26	33	26	33
July 1 – July 31	28	35	27	34
Aug 1 – Aug 31	28	34	28	34
Sep 1 – Sep 30	27	34	27	34
Oct 1 – Oct 31	22	29	21	31
Nov 1 – Nov 7	21	27	19	25

rooting especially in sandy soils may have shown greater impact of mowing height and fertility to increase turfgrass rooting due impart to lower soil temperatures compared to the temperatures recorded during this experiment on finer textured soils.

3.4. Summary and Conclusions

Increasing mowing height and N fertility, cultural practices routinely implemented by turfgrass managers and homeowners, may not be effective management strategies to increase centipedegrass rooting for greater summer drought tolerance in a humid, subtropical climate. This is not to say that implementing higher mowing heights were detrimental to centipedegrass growth or drought response, but that under the conditions of these experiments this practice did not enhance centipedegrass rooting or drought tolerance. In contrast, applications of N at 48.8 kg ha^{-1} lead to slightly less drought tolerant centipedegrass most likely due to increased transpiration rates from denser swards without corresponding increases in rooting. Therefore, following current recommendations of 2.5 to 5 cm mowing heights with low, infrequent N applications appear to be the best management practices for increasing unirrigated centipedegrass survival during droughty periods. Further research is needed to correlate centipedegrass rooting and soil temperature as well as evaluation of cultural practices such as fertility application timing or soil temperature adjustment to enhance centipedegrass rooting and thus drought tolerance.

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Vita

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