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THE EFFECTS OF FOUR PRE-EMERGENT HERBICIDES ON THE ROOTING ARCHITECTURE OF HYBRID BERMUDAGRASS

By

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THE EFFECTS OF FOUR PRE-EMERGENT HERBICIDES ON THE ROOTING ARCHITECTURE OF HYBRID BERMUDAGRASS

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Weed control is essential in managing high quality turfgrasses. Some pre-emergent (PRE) herbicides may pose a negative effect on rooting architecture (total length, surface area, diameter, and mass) of desirable species. Several PRE herbicides work by negatively affecting normal cell division and development. Evaluations were performed to determine the effects of four PRE herbicides (dithiopyr, oxadiazon, pendimethalin, and quinclorac) on hybrid bermudagrass (Cynodon dactylon L. X C. transvaalensis Burtt-Davy) (BG) root architecture. Herbicide treatments were applied to field grown dormant BG in Mid-March of 2008 and 2009. A decrease in root length, and in surface area, was observed at 8 WAT by pendimethalin (55% of control). Twelve WAT the greatest decrease occurred in dithiopyr (40%) and pendimethalin (20%). Sixteen WAT, the greatest decrease was observed by dithiopyr (50%). The results indicate that the PRE's tested can have a negative influence on BG root parameters and possibly water use efficiency.

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CHAPTER I

INTRODUCTION

Pest management is a critical aspect of a turfgrass manager's job. Whether a sod farmer, golf course superintendent, or athletic field manager a turfgrass manager must be able to quickly identify a problem and solve it promptly before too much damage occurs. Problems can vary greatly and may be frequent when managing high quality turf. Weeds can be quite problematic but can be controlled by a variety of methods including herbicides. Herbicides are effective tools in maintaining high quality turfgrasses, especially when used with other best management practices to suppress weed infestation. Every herbicide sold in the U.S. has an herbicide label which details the specific intention for the herbicide and the legal way in which it can be used. Further information on the label includes possible effects on the non-target, or desirable, species. Negative effects on desirable species can occur on all plant parts. Some herbicides that are persistent for long periods of time in the soil may have a negative effect on rooting parameters of the desirable species, while other chemicals can cause foliar burn.

There are many reasons for controlling weeds in turfgrasses. Weeds (defined as a plant in an undesirable location) pose negative influences on turfgrasses, including plant to plant competition - the struggle for plants to out-compete neighboring plants for resources. Various weeds may have characteristics that allow them to prevail in a competitive situation with turfs, and controlling these weeds will enable more successful use of resources by a turf. Also, weed plants may harbor pests that could pose a threat to desirable turfgrasses. Lastly, weeds may interfere with ball roll or endanger athletes in a sports situation such as a golf green or athletic field. A turf manager's job requires them to provide a desirable and safe playing surface free from interference of debris and uneven playing surfaces, including weeds. Allowing pests to establish and then controlling them can leave voids in the turfgrass canopy that are unsightly and may allow other pests to establish (Fry, 1986). Maintaining a healthy, dense stand of turf is the best defense in weed management, however, pesticide use may be required to ensure a high quality turf (Turgeon, 2005).

There are numerous products available to control weeds in a variety of turf species. Products differ in active ingredient, formulation, and application timing. Depending upon the product, an herbicide can be applied prior to weed establishment, or after the pest has established. A product that is applied before weed germination is described as a pre-emergent herbicide (PRE), whereas a product applied after the weed has emerged and established is coined a post-emergent herbicide (POST).

The combination of PRE and POST herbicide use has become an effective and reliable tool for turf managers in the southeastern U.S. Pre-emergent herbicides must be applied to the entire area of desired control before weed seed germination. The intent of a PRE application is not to prevent seed germination, but to kill the young weed as it begins to grow. These herbicides require germination to be effective (Rossi, 1992). Following germination, the seedling absorbs the herbicide present in the top two inches of soil (Rossi, 1992). Pre-emergent herbicides are typically applied in the spring before soil temperatures become favorable for summer annual weed establishment (McCarty and Murphy, 1994). Conversely, to control winter weeds, the PRE must be applied in late summer or fall so the herbicide will persist in the soil when the weed seed germinates. Applying a PRE to an actively growing stand of turf does not pose a high risk of injury or discoloration like some POST applications may cause (Bingham, 1974; Bhowmik, 1987). Spring applications are generally made on dormant turf in the southeastern U.S., unless over-seeding has occurred in the treated area.

A PRE is chemically designed to remain in the soil for extended periods of time (Zimdahl et al., 1984). The persistence of a PRE will vary depending upon the soil texture, the product chemistry, cultivation practices, and soil temperature and moisture conditions (Zimdahl et al., 1984). These products are designed to adhere readily to clay particles and organic matter in the soil, so an increase in clay or organic content could result in longer life of the herbicide in the soil (Appleby and Valverde, 1989). Conversely, a sandy soil or a low clay soil may allow for quicker degradation or leaching of the product (Appleby and Valverde, 1989). Other factors that can affect the persistence include microbial activity, soil temperature, depth, and light penetration (Bhowmik and Bingham, 1990; Schleicher et al., 1995).

Pre-emergent herbicides come in a variety of formulations and control weeds through various modes of action. The mode of action is the specific way the herbicide inhibits normal growth and development of the plant. This may include mimicking a plant growth substance, inhibiting a physiological function, or interrupting normal cell division in the plant (Tu et al., 2001). Herbicides are classified into families depending on the chemistry of the product and the mode of action. There are several families of PRE herbicides available for use in the turf industry. It is important for a turf manager to understand the difference between the various herbicide families, and make decisions of use based upon the goal of the application. Continuous use of the same herbicide family can result in the development of resistant or tolerant weeds which may not be affected by the herbicide or the mode of action (Hutto et al., 2004). To prevent the development of resistance, a turfgrass manager should alternate the use of various herbicide families that will control the same weed(s) (Hutto, 2004).

Mitotic inhibitors are an herbicide family which acts by suppressing normal cell division in the roots, and thus growth, of the newly germinated plant (Fagerness et al., 2002). Pendimethalin is a mitotic inhibitor in the dinitroaniline (DNA) family. This herbicide causes interruption of growth in the plant resulting in the young plant quickly expending its stored energy and eventual death of the plant (Fagerness et al., 2002). Dinitroaniline herbicides have been shown to affect root and rhizome development (Fishel and Coats, 1994). Dithiopyr is another PRE herbicide that acts as a mitotic inhibitor in the plant, but the specific mode of action varies from that of pendimethalin. Dithiopyr acts as an auxin mimic in the plant and interrupts normal cell division by creating disorganized and uncontrolled growth of the plant (Tu et al., 2001). Herbicides that control weeds by this means are grouped in the pyridine family. Quinclorac is also believed to mimic auxin, but the specific mode of action is not completely understood (Vencill, 2002). Furthermore, quinclorac is not generally classified into a formal herbicide family. Oxadiazon is another commonly used PRE herbicide in the southeastern U.S. Oxadiazon’s primary target site is the protoporphyrinogen oxidase (PPO) enzyme associated with chlorophyll biosynthesis (Vencill, 2002).

Herbicides such as the previously mentioned PRE herbicides work by forming a chemical barrier in the top two inches of the soil (Rossi, 1992). This is also the region where the desirable plants are attempting to establish new roots. Warm-season grasses may be vulnerable to root damage during spring root re-generation, which coincides with proper timing for application of PRE herbicides (Engel and Ilnicki, 1969). The products are generally applied to dormant turf which minimizes the risk for foliar burn, but the chemical barrier is present in the soil when plants begin to break dormancy and new root initiates begin to form.

Some POST applications are known to cause minor burning and discoloration of healthy plants. However, the application of some PRE herbicides are thought to be less injurious to established turf, though the ability to detect subtle differences in rooting remains a critical void in turfgrass research (Rossi, 1992). Many of the PRE herbicides are from the DNA family. These herbicides inhibit cell division in germinating seedlings; however, they also inhibit mitosis in the roots of emerging susceptible plants (Bhowmik, 1990). In a study by Fishel (1994), the use of DNA herbicides and their effects on bermudagrass (Cynodon spp) (BG) turfs were evaluated and determined to have different injuries on BG turf. Fishel (1994) showed a reduction in the number of total roots in plants treated with prodiamine or dithiopyr. However, the reduction in root number did not occur until 4 & 8 weeks after initial treatment. In the same study, pendimethalin showed no consistent pattern of root reduction. Fishel (1994) determined pendimethalin to be ‘intermediate’ with respect to prodiamine and dithiopyr in the reduction of normal root mass and the production of some malformed roots.

Sullivan (2000) reported total root length and N uptake rates are positively correlated. This may be linked to water uptake because nitrogen enters the plant via mass flow. Furthermore, research has shown that the decreased number of total roots and the decreased average root length of creeping bentgrass (Agrostis stolonifera L.) under heat-stress in the Southern U.S. limited plant access to water and nutrients in the soil (Jordan et al., 2003). Water use for turfgrass management has come under high scrutiny in times of decreased rainfall and extended droughts in the southeastern U.S. Water use restrictions and bans on irrigating turfgrasses have been problematic for turfgrass managers. Water is a limiting factor in managing high quality turfgrasses. Without water, plants will have reduced photosynthesis, turgor, and nutrient uptake often resulting in stressed plants that will be more susceptible to secondary diseases and pest damage.

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CHAPTER II

THE EFFECTS OF FOUR PRE-EMERGENT HERBICIDES ON THE ROOTING ARCHITECTURE OF ‘TIFWAY’ BERMUDAGRASS

ABSTRACT

Weed control is essential for managing high quality turfgrasses. Controlling weeds not only improves turf uniformity and density, but also reduces plant competition for light, water, and nutrients. Many cultural practices help reduce weed establishment, but in some situations herbicide use is required. Pre-emergent (PRE) herbicides may pose a negative effect on root architecture (total length, surface area, diameter, and mass) of the desired turfgrass species. Several PRE herbicides work by negatively affecting cell division and development. Turfgrasses break dormancy in the spring and produce new roots that must penetrate the chemical barrier and may be susceptible to damage. Evaluations were performed to determine the affect of four PRE herbicides (dithiopyr, oxadiazon, pendimethalin, and quinclorac) on hybrid bermudagrass (Cynodon dactylon L. X C. transvaalensis Burtt-Davy) (BG) root architecture. Herbicide treatments were applied to field grown dormant BG in Mid-March of 2008 and 2009. Root samples were harvested and divided into top and bottom profiles at a depth of 7.6 cm, and root parameters determined using the Win-Rhizo^{tm} root scanning system. The roots were evaluated 2, 4, 8, 12, and 16 weeks after treatment (WAT). Results indicate a decrease in root biomass and root architecture parameters. The greatest decrease in root length, and surface area, was observed at 8 WAT by pendimethalin (55% of control). Twelve WAT parameters were not as severely affected, and the greatest decrease in root length and surface area occurred in dithiopyr (40%) and pendimethalin (20%), but other treatment effects were minimal. Sixteen WAT, the greatest decrease in parameters were observed by only dithiopyr (50%). The results indicate that the PRE's tested can negatively influence BG root parameters into the summer growing season.

INTRODUCTION

Controlling weeds is a major concern in managing high quality turfgrass. Weeds have a negative effect on the overall quality, uniformity, and density of turfgrasses as well as compete for resources (Turgeon, 2005). Various weeds have characteristics that may allow them to effectively compete for water and nutrients. Controlling these weeds will allow for more successful use of resources by the turfgrass. A turfgrass manager's job requires them to provide a desirable and safe playing surface free from interference of debris and uneven playing surfaces, including weeds. Maintaining a healthy, dense stand of turf is considered the best defense in weed management, but sometimes herbicide use is required.

The options for controlling weeds with herbicides vary depending upon species of turfgrass and other factors. Each treatment should be implemented in conjunction with best management practices, but should not be relied upon solely to control weeds. Cultural practices such as proper mowing height, adequate and balanced fertility, and the management of soil compaction, drainage, and irrigation help to combat weed infestations (Busey and Johnston, 2006). Irrigation requirements vary among species of turf, but adequate irrigation for any species is essential in maintaining a high quality, dense stand of turf that can combat pest infestation.

Irrigation availability is typically not a fore-thought of a turfgrass manager unless the availability is limited or restricted. In areas of the Southeastern U.S. and other regions that have experienced extended drought occurrences, the lack of available irrigation water has become a reality. If irrigation sources are scarce or limited, it is imperative that resources are utilized as efficiently as possible while still providing an adequate amount of irrigation to maintain plant health. Eliminating competition for resources is just one way in which turfgrass managers can maximize the use of the irrigation applied to turfgrass. However, eliminating pests that have established, or have a history of establishing in an area, may require the use of an herbicide. Busey and Johnston (2006) concluded that cultural practices alone were not sufficient to maintain a monoculture of St. Augustinegrass (Stenotaphrum secundatum (Walt.) Kuntze) over a three year period and herbicides must be used to keep a stand weed free. The authors also concluded that implementing best management practices reduced the weed presence which in turn reduced the use of herbicides, but no cultural practice(s) alone provided acceptable levels of weed control. Turgeon (2005) describes the proper use of pesticides as part of a sound cultural program to help ensure high-quality turf. Eliminating the competition from undesirable plants will allow for more efficient use of resources as well as maintain an aesthetically pleasing and uniform turfgrass (Busey and Johnston, 2006; Turgeon, 2005).

Numerous products are available to control weeds in various turfgrasses. Products differ in characteristics such as active ingredient, formulation, and application timing, species controlled, and many other aspects. The application timing describes when the product should be applied to best control the pest(s). In the case of a pre-emergent herbicide (PRE) a product can be applied prior to a weed establishing and becoming a pest. A product that is applied after the pest has established and should be removed or controlled is a post-emergent (POST) herbicide.

It is important to apply a PRE before weed seed germination so that it can enter the soil solution and be readily available for plant uptake upon seed germination. The intent of a PRE application is not to prevent germination of seeds, but the herbicide requires germination to be effective (Rossi, 1992). Following germination, the seedling absorbs the herbicide present in the top 5 cm of soil (Rossi, 1992). To control summer annual weeds, PRE herbicides are applied in the spring prior to soil temperatures becoming favorable for weed establishment (McCarty and Murphy, 1994). Warm-season grasses may be vulnerable to root damage during spring root re-generation, which coincides with proper timing for application of PRE herbicides (McCullough et al., 2007). Spring applications are generally made on dormant turf in the southeastern U.S., unless over-seeding has occurred in the treated area.

Pre-emergent herbicides are applied to the turf and irrigated, or incorporated into the soil in a pre-plant situation, to form a protective chemical barrier in the soil that weeds will contact during emergence (Gasper et al., 1994). Contact with this barrier by emerging roots allows for absorption of the active ingredient and thus controls the plant from establishing as a pest. Using a PRE product may greatly decrease the amount of POST products needed when managing high quality turf.

Following application, a PRE will remain in the soil for extended periods of time. The length of time a PRE will remain in the soil varies among products, but depends on the herbicide rate, cultivation practices, soil physical and chemical properties, soil temperature, and soil moisture (Bhowmik and Bingham, 1990). These products are designed to adhere readily to soil colloids, and an increase in clay or organic content could result in longer life of the herbicide in the soil (Appleby and Valverde, 1989). The dinitroanaline family of herbicides strongly adsorb to clay colloids and organic matter due to their high potential for hydrogen bonding (Gasper et al., 1994). Conversely, a sandy soil or a low clay soil may allow for quicker degradation or leaching of the product.

The intended use of a PRE herbicide is to provide extended control of weeds without negatively affecting the desired species. Applying a PRE in the spring should give the turfgrass manager acceptable control of weeds through the summer growing season (Bingham et al., 1985). However, spring applications of PRE herbicides coincide with spring root re-generation of warm-season turfgrasses (Engel and Ilnicki, 1969). The growing regions of the desirable roots are located at the tip of the root. A root initiate - a root that forms from a node of a rhizome or stolon and begins to penetrate the soil - will inevitably contact the chemical barrier if it is present in the shallow depths of the soil.

The objective of this research was to determine if PRE herbicides affect the root architecture (total root length, surface area, diameter, and mass) of BG and to quantify the duration of any damage to the root system.

MATERIALS AND METHODS

Field research was conducted at Mississippi State University's R.R. Foil Plant Science Research Facility in Starkville, MS. 'Tifway' bermudagrass (Cynodon dactylon L. Pers. x C. transvaalensis Burtt-Davy) was established vegetatively in September, 2007 on a 15.2 x 15.2m plot on 90-10 sand reed-sedge peat mix. Plants were adequately fertilized and mowed to 1.9 cm to achieve nearly full cover before the winter of 2007. The pH of the soil was 6.7 in February 2008 and 7.2 in March, 2009.

Four PRE treatments were applied at labeled rates – dithiopyr 1-EC (Dow AgroSciences, Dimension^{tm}) 0.318 kg ai ha^{-1}, oxadiazon 2-G (Bayer, Ronstar^{tm}) 4.39 kg ai ha^{-1}, pendimethalin 3.8-CS (BASF, Pendulum^{tm}) 3.273 kg ai ha^{-1}, and quinclorac 75-DF (BASF, Drive^{tm}) 2.242 kg ai ha^{-1}. Each treatment was randomly assigned to its respective plot in a randomized complete block design with four replications. Herbicides were applied 15 March 2008, and 12 March 2009 and all herbicides were applied at the same time and irrigated for ten minutes per label directions. Treatments were applied to the same plot both years to negate any residual herbicide effects. The application dates for each year were based on common PRE application timings for the region (U.S.D.A. hardiness zone 7b). No other means of chemical weed control were applied throughout the experiment. Treatments were applied using a backpack CO_2-pressured sprayer calibrated to 284 L ha^{-1} with 45 cm nozzle spacing and 4 nozzles on the boom. Each treatment was compared to an untreated control, and all plots received equal irrigation, light, fertility, and mowing. A complete (13N-5.7P-10.8K) fertilizer was added to the plots on Apr 1 and May 1, 2008 and 2009 at a rate of 50 kg N ha^{-1}. Additionally, ammonium nitrate (34N-0P-0K) was added bi-weekly beginning 15 May until 1 July in both years at a rate of 25 kg ha^{-1} for a total amount of 195 kg ha^{-1} for 16 weeks. No other management practices, such as verti-cutting or aerification were performed during the extent of the research to prevent disturbing the herbicide barrier in the soil. Plants were mowed with a reel mower at a height of 1.9 cm twice a week and the clippings returned to the turfgrass. Irrigation was added as necessary to prevent wilting.

Root samples were randomly harvested using a soil profiler (Turf-Tec International©, Tallahassee, FL) that removed a turf and soil slab 1.9 x 10 x 15.2 cm at 2, 4, 8, 12, and 16 weeks after treatment (WAT). Sampling location and orientation within the plots were determined by blindly tossing a 15 cm linear object into the plot and sampling where the object fell and parallel to the orientation of the object. No samples were taken in the presence of weeds, or, in the outer 30 cm perimeter of the plots to prevent possible observation of the treatment effects of the herbicide in the neighboring plot. Slabs were removed intact and returned to the lab for processing. The above-ground vegetation was removed at the plant-soil interface and discarded. Samples were separatted at 7.6 cm into sub-samples and washed of all foreign material by hand except for BG roots. Washed roots were stored in de-ionized water at 3°C until scanning.

Roots were analyzed on the Win-rhizo^{tm} (Regent Instruments, Nepean, ON) root scanning system. Samples were submerged and gently agitated in de-ionized water twice to remove any leftover debris. Roots were then placed in a 0.1% v/v solution of azure blue and de-ionized water for five minutes to stain followed by rinsing. Stained roots were then placed on a 12.5 x 20 x 1.5 cm clear plastic tray and floated in de-ionized water. Roots were hand separated and then digitally scanned with the root scanning software. Analyses of the roots included total root length (TRL), surface area (SA), and average root diameter (ARD). After scanning, root samples were oven-dried at 74°C for 24 hr and mass (mg) determined gravimetrically.

The experimental design was a randomized complete block design with four replications. Plot size was 1.9 x 3.8m plots per block. One untreated control plot received the same cultural practices as the treated plots, but no herbicide was applied. Observations on root parameters were recorded at the appropriate sampling interval, and the data separated by general linear model at $p=0.05$ level of significance using Fisher's Protected LSD with Statistical Analysis Software (SAS 9.2, 2007, Cary, NC). Correlations between root architecture parameters were determined using Pearson Correlation Coefficients.

RESULTS AND DISCUSSION

Analysis of the data revealed a treatment-by-year interaction ($p \leq 0.05$) for all root architecture parameters, thus the data are presented separately for each year.

Root Mass

In 2008, no treatment resulted in a reduction in root biomass until 8 WAT (Table 2.1). Only pendimethalin significantly reduced root biomass >70% in comparison to the control 8 WAT, but no other significant reductions in root biomass were observed until 12 WAT. At 16 WAT, a drastic reduction in root biomass of all treatments was observed due to root observations of plants under severe water stress from an irrigation system failure. Dithiopyr significantly reduced root biomass in comparison to the control and the other herbicide treatments at this sampling date. Dithiopyr reduced root biomass nearly 65% compared to the untreated plants, and >50% of the other herbicide treatments.

Table 2.1 The effect of chemical treatment on dry root mass summed across sampling depths at all sampling dates in 2008.

	Sampling Interval (WAT[x])				
	2	4	8	12	16
Treatment	Root Mass[y] (mg)				
Control	78.0a[z]	69.8a	96.1a	192.8a	114.3a
Dithiopyr	41.8a	55.9a	64.4ab	88.2a	39.7b
Oxadiazon	66.7a	50.7a	66.6a	144.3a	81.0a
Pendimethalin	77.5a	43.3a	26.6b	119.0a	93.9a
Quinclorac	37.7a	38.3a	62.1ab	140.4a	110.1a

[x] WAT=weeks after treatment; Treatments applied 15 Mar, 2008.

[y] Mean root mass (mg) of both sampling depths summed together (0-15.2cm).

[z] Means with the same letter within the same column are not significantly different (P=0.05).

In 2009, reductions in root biomass were observed at every sampling interval with the exception of 4 WAT (Table 2.2). Data observed in 2009 has nearly twice the root biomass than the previous year at each sampling interval. This is likely due to a longer growing period of the BG in 2009. The trends between the two years are similar, and although not always significant, the general trend for root biomass reduction shows quinclorac had the least effect on bermudagrass roots, followed by oxadiazon, dithiopyr and pendimethalin, respectively. Oxadiazon and quinclorac did not significantly reduce root mass below the control for any sampling interval in either year of the study. Results presented herein tend to agree with the findings of Fishel and Coats (1994) which reported oxadiazon to be safer on BG roots in comparison to mitosis inhibiting herbicides such as dithiopyr and pendimethalin. Fishel and Coats (1994) reported early reductions (2 and 4 WAT) in root mass with dithiopyr, but the results do not evaluate effects longer than 8 WAT. The results presented herein indicate a significant reduction in root mass by dithiopyr 16 WAT in 2008, although the temporary irrigation failure may have exaggerated the effects. Significant reductions in root mass by dithiopyr were observed at 8, 12, and 16 WAT in 2009, and suggest prolonged negative effects on root mass well into the summer growing season. The trend in root mass reduction in 2009 is similar to the previous year, in that dithiopyr reduced root mass >60% in comparison to the control and nearly 50% the amount of the other treatments at the final sampling interval.

Table 2.2 The effect of chemical treatment on dry root mass summed across sampling depths at all sampling intervals in 2009.

	Sampling Interval (WAT [x])				
	2	4	8	12	16
Treatment	Root Mass[y] (mg)				
Control	128.7ab[z]	155.4a	200.5a	175.5ab	224.6a
Dithiopyr	93.4b	92.2a	111.9b	92.3c	97.0b
Oxadiazon	104.0abc	106.5a	159.4ab	157.3bc	174.3a
Pendimethalin	67.0c	87.7a	102.8b	144.3bc	181.7a
Quinclorac	140.8a	108.9a	182.1a	237.4a	197.3a

[x] WAT=weeks after treatment; Treatments applied 12 Mar, 2009.
[y] Mean root mass (mg) of both sampling depths summed together .
[z] Means with the same letter within a column are not significantly different (p=0.05).

Root Length

In 2008, no significant reductions in total root length (TRL) were observed until 8 WAT (Table 2.3). This sampling date coincides with warmer day and night temperatures of Mid-May in Central Mississippi and more active BG growth and development at the increasing temperatures (McCarty and Miller, 2002). The high and low temperature at the

8 WAT sampling date was 23°C & 17°C, respectively. Herbicide treatment effects may not be evident until plant growth and activity increase with warmer temperatures and increased light intensities. All herbicide treatments reduced TRL compared to the control at the 8 WAT sampling date. At this sampling date, pendimethalin incited the largest reduction in TRL. Significant reductions in TRL were not observed 12 WAT, but dithiopyr treated plots had a significant reduction in TRL 16 WAT. No other herbicide treatment effects were observed.

Table 2.3 The effect of chemical treatment on total root length summed across sampling depths at all sampling intervals in 2008.

	Sampling Interval (WAT [x])				
	2	4	8	12	16
Treatment	Total Root Length[y] (cm)				
Control	1028.1a[z]	826.9a	1273.6a	1305.7a	1261.3a
Dithiopyr	603.5a	713.6a	941.9b	784.2a	637.9b
Oxadiazon	799.2a	701.3a	965.5b	1250.1a	1095.8a
Pendimethalin	895.2a	622.7a	559.3c	1081.6a	1093.7a
Quinclorac	599.5a	596.6a	782.4bc	1495.8a	1420.9a

[x] WAT=weeks after treatment; Treatments applied 15 Mar, 2008.
[y] Mean root length (cm) of both sampling depths summed together (0-15.2cm).
[z] Means with the same letter within a column are not significantly different (p=0.05).

In 2009, significant reductions of TRL were observed at every sampling interval except 4 WAT (Table 2.4). Two WAT, pendimethalin significantly reduced TRL from the control. Bingham et al. (1988) report negative effects on root growth were generally observed immediately following application of pendimethalin on cool-season turfgrass species. The results presented herein agree with Bingham et al. (1988) and also indicate immediate effects on BG roots. The effects of dithiopyr, oxadiazon and quinclorac were not statistically different from the control. Dithiopyr did reduce TRL greater than quinclorac and oxadiazon. Total root length was affected the greatest 8 WAT by pendimethalin and dithiopyr. Oxadiazon and quinclorac were not different from the control, although the effects of oxadiazon were not statistically different from reductions in dithiopyr treated plants. Both 12 and 16 WAT, the data revealed a significant reduction in TRL by dithiopyr. Treatment x year interaction was detected in TRL data, but the trends of TRL are similar in both years.

The differences between years of the research may be attributed to the juvenility of the BG plants in the first year. In 2008, treatments were applied to test plots that had not reached 100% plant cover. It is speculated that as the plant cover increased, a larger portion of the root system samples were represented by new roots, than if the plots were fully grown in. Bermudagrass is both rhizomatous and stoloniferous (Turgeon, 2005). As the nodes of the rhizomes and stolons of BG develop and contact the soil, new root initiates are formed in the shallow depths of the soil (Turgeon, 2005). Test plots that did not achieve 100% cover prior to treatment application may have produced greater numbers of juvenile roots after spring green-up and treatment application due to the spreading and anchoring of the rhizomes and stolons. This may explain why no significant differences in TRL were observed in 2008 until 8 WAT but only 2 WAT in 2009 there were negative affects on TRL. The growing regions of the new roots may have been subjected to contact with the treatments in the soil at a later date than the plants in 2009 due to the spreading and formation of roots in a previously un-covered area.

Turgeon (2005) characterized BG as having an annual root system. However, it is difficult to understand exactly how much of the root system is carried over from year to year (Beard and DiPaolo, 1978). The annual re-generation of the BG root system begins within one week following spring green-up with the discoloring and dieback of the intact root system (Beard and DiPaolo, 1978). The new root initiates form from the nodes of rhizomes and stolons and begin to penetrate the soil (Turgeon, 2005). According to Beard and DiPaolo (1978) it takes approximately 20 days following new root initiation for an un-affected root to reach a depth of 30cm. In 2009, all treatments were applied to mature test plots that had achieved 100% cover and had a fully established root system. New root initiates contacted treatments present in the soil and may have been affected earlier in the observation period and at subsequent intervals due to the annual re-generation of the BG root system following spring green-up. Reductions in TRL occurred early in 2009 at 2, 4, and 8 WAT by most treatments, but recovery comparable to the control was observed at 12 and 16 WAT by all treatments except for dithiopyr. Conversely, in 2008 no treatment effects were observed until 8 WAT and recovery by most treatments in comparison to the control was observed 12 WAT. In both years, dithiopyr was the only treatment to reduce TRL at 16 WAT, and the reductions were similar for both years with reductions of 51% and 46%, respectively.

Table 2.4 The effect of chemical treatment on total root length of the entire sampling depth and area at 5 sampling intervals in 2009.

	Sampling Interval (WAT[x])				
	2	4	8	12	16
Treatment	Total Root Length[y] (cm)				
Control	1571.7ab[z]	1756.3a	1806.9a	1710.7a	1833.5a
Dithiopyr	1240.0bc	1238.8a	1198.3bc	737.0b	850.4b
Oxadiazon	1425.5a	1468.2a	1602.9ab	1445.1a	1488.7a
Pendimethalin	1105.7c	1089.7a	1109.9c	1274.1a	1505.8a
Quinclorac	1745.2a	1319.0a	1681.5a	1707.4a	1542.7a

[x] WAT=weeks after treatment; Treatments applied 12 Mar, 2009.
[y] Mean root length (cm) of both sampling depths summed together (0-15.2).
[z] Means with the same letter within a column are not significantly different (p=0.05).

Results from each year had similar trends in reductions of roots observed only in the upper profile, and total root length observations. In 2008, TRL in the upper profile was significantly reduced by treatment(s) at 8, 12, and 16 WAT (Table 2.5). Eight WAT, pendimethalin had the greatest affect on root length of all treatments, reducing root length nearly 60% in comparison to the control. Dithiopyr and quinclorac both significantly reduced root length from the control, and pendimethalin had significantly less TRL than all other treatments. Oxadiazon was the only treatment that did not reduce root length from the control 8 WAT in 2008. Likewise, 12 WAT dithiopyr and pendimethalin were again similar in root length reductions; however, pendimethalin did not significantly reduce root length below the control level. Quinclorac treatments returned to control length and were not negatively affected 16 WAT. Oxadiazon did not affect root length at any sampling date in comparison to control plants. At the final sampling interval of 2008, only dithiopyr significantly reduced root length below the control level. All other treatments recovered to the control level 16 WAT

Table 2.5 The effect of chemical treatment on total root length of the upper (0-7.6cm) sampling depth at 5 sampling intervals in 2008.

	Sampling Interval (WAT [x])				
	2	4	8	12	16
Treatment	Root Mass[y] (mg)				
Control	845.4a[z]	663.0a	1035.7a	1008.1ab	945.5ab
Dithiopyr	454.0a	599.0a	739.2b	533.2c	408.4c
Oxadiazon	610.4a	561.3a	815.9ab	968.4ab	886.1ab
Pendimethalin	658.8a	486.9a	409.4c	712.8bc	767.7b
Quinclorac	498.2a	381.8a	688.8b	1126.1a	1049.5a

[x] WAT=weeks after treatment; Treatments applied 15 Mar, 2008.

[y] Mean root length (cm) of the upper (0-7.6cm) sampling depth.

[z] Means with the same letter within a column are not significantly different (p=0.05).

In 2009, all sampling intervals showed differences in root length among treatments (Table 2.6). Two WAT, dithiopyr and pendimethalin both significantly reduced root length in comparison to the control. The root lengths of oxadiazon and quinclorac were not significantly different from the control level or dithiopyr. The effects of all treatments were similar 4 and 8 WAT. Quinclorac and oxadiazon treatments again had minimal effect on root length, and pendimethalin significantly reduced root length compared to all other treatments. Dithiopyr also significantly reduced root length, but the effects of the treatment were not different than those of quinclorac and oxadiazon 4 WAT, but were significantly different 8 WAT. Twelve WAT, dithiopyr had the greatest affect on root length of all treatments, followed by pendimethalin. No other treatment reduced bermudagrass root length at this sampling date. Oxadiazon and quinclorac did not significantly reduce root length from the control at any sampling interval, and dithiopyr was the only treatment to significantly reduce root length at every sampling date with respect to the control

In both years, treatments were applied to dormant bermudagrass. Spring PRE applications typically coincide with root growth regeneration of warm-season grasses such as BG (McCullough et al., 2007). Applying treatments before active plant growth subjects the new root initiates to the possibility of contacting the herbicide in the soil several days after treatment resulting in a negative effect (Fishel and Coats, 1994). The persistence of these PRE treatments, due to low water solubility and adsorption to organic material and soil colloids, allows for contact with new roots well into the summer growing season (Bhowmik and Bingham 1990). The greatest affect on root architecture by treatments was observed 8 WAT in both years by dithiopyr, pendimethalin, and oxadiazon. This sampling date coincides with active growth of the plant in the early summer months, or the time that the plants may be trying to re-generate a root system for the summer growing season. Suman and Gajbhiye (2002) determined the persistence of dithiopyr to be greater than 90d on an alluvial soil, and this may explain why dithiopyr negatively affected root parameters at early sampling dates, as well as produced treatment effects 16 WAT when no other treatment negatively affected root length at the later sampling date. The general trend of root length reduction is similar in both years, though the differences are not always significant. Treatment effects differ early in the observation period, but by the final sampling interval, all treatments except dithiopyr recovered to the control. At 16 WAT dithiopyr reduced root length 57% and 55% of the control in 2008 and 2009, respectively. The trend in root length reduction in the upper profile follows a similar trend as root length reductions of observations on the total sampling area.

Table 2.6 The effect of chemical treatment on total root length of the upper (0-7.6cm) sampling depth at 5 sampling intervals in 2009.

	Sampling Interval (WAT[x])				
	2	4	8	12	16
Treatment	Root Length[y] (cm)				
Control	1259.0a[z]	1394.7a	1430.5a	1387.7a	1469.0a
Dithiopyr	870.5bc	932.3bc	937.8bc	596.9c	656.3b
Oxadiazon	1127.7ab	1175.5ab	1312.1ab	1190.1ab	1208.2a
Pendimethalin	803.5c	762.1c	817.9c	929.8bc	1141.4a
Quinclorac	1400.9a	1119.9abc	1418.3a	1396.4a	1275.4a

[x] WAT=weeks after treatment; Treatments applied 12 Mar, 2009.
[y] Mean root length (cm) of the upper (0-7.6cm) sampling depth.
[z] Means with the same letter within a column are not significantly different (p=0.05)

Pre-emergent herbicides remain held tightly to soil colloids near the soil surface, so roots deeper in the soil profile remain unaffected by the presence of the treatments. At the lower sampling depth (7.6-15.2 cm), no significant reductions in root length were observed for any treatment at any sampling interval (Tables 2.7 and 2.8). Plants were managed similarly during both years to minimize several variables that may affect rooting to minimize plant stress. Initiation of treatments in 2008 occurred when the turfgrass was near 75% cover. As the plants began active growth, new root initiates form from nodes to anchor the plant in the newly covered area. As reported, the untreated control plants had significantly lower levels for each rooting parameter in 2008 with respect to 2009. Sixteen WAT in 2008, the control plants had a root system that was comparable to root parameters evaluated 2 WAT in 2009. Management practices are implemented to encourage a deep, healthy root system that will sustain turf through drought situations (Levitt, 1980). Deeper roots may be able to access water held in the soil at deeper depths after long periods without sufficient irrigation events. The data presented herein suggests maintaining a deep root system may alleviate or minimize negative influences of PRE herbicides on root architecture parameters of BG. In the previous section, effects of treatment(s) on root length are observed at the upper (0-7.6 cm) soil depth at various sampling dates, but the lower (7.6-15.2 cm) soil depths (Tables 2.7 and 2.8) remain unaffected throughout all sampling dates in both years. This may be attributed to the prior advancement of the growing region of the root deeper into the soil than the area the herbicide was applied (Fishel and Coats, 1994). Normal root growth and development of the existing roots is not inhibited or altered by the treatments in the soil because the meristematic region of the roots have penetrated the soil deeper than the chemical barrier prior to chemical application, or originated below the herbicide layer. Newly formed roots that penetrate the soil prior to treatment application may remain unaffected, but roots penetrating the soil after treatment application may contact the chemical barrier as the root advances into and through the soil (Fishel and Coats, 1994).This may explain the absence of treatment effects on the roots in the lower sampling depth for the duration of the research.

Table 2.7 The effect of chemical treatment on total root length of the lower (7.6 – 15.2cm) sampling depth at 5 sampling intervals in 2008.

	Sampling Interval (WAT ^{x})				
	2	4	8	12	16
Treatment	Root Length^y (cm)				
Control	182.8a^z	163.9a	237.9a	297.6a	315.9a
Dithiopyr	149.5a	114.4a	202.7a	251.1a	229.5a
Oxadiazon	188.8a	140.1a	150.0a	281.7a	209.7a
Pendimethalin	236.4a	135.8a	149.6a	368.8a	325.9a
Quinclorac	101.2a	214.8a	93.7a	369.7a	371.4a

^{x}WAT=weeks after treatment; Treatments applied 15 Mar, 2008.
^{y}Mean root length (cm)of the lower (7.6-15.2cm) sampling depth.
^{z}Means with the same letter within a column are not significantly different (p=0.05).

Table 2.8 The effect of chemical treatment on total root length of the lower (7.6 – 15.2cm) sampling depth at 5 sampling intervals in 2009.

	Sampling Interval (WAT ^{x})				
	2	4	8	12	16
Treatment	Root Length^y (cm)				
Control	312.7a^z	361.7a	376.5a	323.0a	364.5a
Dithiopyr	369.5a	306.5a	260.5a	140.0a	194.1a
Oxadiazon	297.8a	292.8a	290.8a	254.9a	280.6a
Pendimethalin	302.1a	327.7a	292.0a	344.3a	364.5a
Quinclorac	344.2a	199.1a	263.2a	310.9a	267.3a

^{x}WAT=weeks after treatment; Treatments applied 12 Mar, 2009.
^{y}Mean root length (cm)of the lower (7.6-15.2cm) sampling depth.
^{z}Means with the same letter within a column are not significantly different (p=0.05).

Total Surface Area

In 2008 the reduction in total surface area (TSA) was similar to the trend of TRL - no significant reductions in TSA were observed until 8 WAT (Table 2.9). All treatments significantly reduced TSA 8 WAT. At this sampling interval, pendimethalin had the greatest reduction in TSA, followed by quinclorac, dithiopyr, and oxadiazon, respectively. At 12 WAT, quinclorac and oxadiazon treatments returned to TSA similar to the control and dithiopyr and pendimethalin both had significantly reduced TSA compared to the control. Dithiopyr reduced TSA more than all other treatments at 12 and 16 WAT, and was the only treatment to reduce TSA below the control at the final sampling date.

Table 2.9 The effect of chemical treatment on total surface area of both sampling depths summed at 5 sampling intervals in 2008.

	Sampling Interval (WAT[x])				
	2	4	8	12	16
Treatment	Surface Area[y] (cm^{2f})				
Control	93.6a[z]	76.8a	132.3a	154.1ab	141.8a
Dithiopyr	50.2a	66.5a	88.4b	84.6c	57.9b
Oxadiazon	75.7a	63.5a	91.5b	149.0ab	114.7a
Pendimethalin	86.0a	52.9a	45.8c	108.0bc	116.7a
Quinclorac	50.5a	49.4a	78.7bc	159.2a	158.3a

[x] WAT=weeks after treatment; Treatments applied 15 Mar, 2008.

[y] Mean surface area (cm^2) of both sampling depths (0-15.2cm) summed together.

[z] Means with the same letter within a column are not significantly different (p=0.05).

In 2009, reductions in TSA occurred at every sampling date except 4 WAT (Table 2.10). Two WAT, dithiopyr and pendimethalin had significantly lower TSA than the control roots. Quinclorac and oxadiazon were not different from the control; however, oxadiazon effects were reduced compared to the control and quinclorac levels. At 8 WAT, pendimethalin and dithiopyr had the greatest TSA reductions. The persistence of PRE herbicides is a characteristic that allows for extended control of weeds well after herbicide treatment to the soil (Gasper et al., 1994). Pendimethalin and dithiopyr are both characterized as being persistent in the soil, and both treatments had the greatest affect on TSA at later sampling dates in both years. Zimdahl et al. (1984) report greater than 60%

of the applied pendimethalin (µg/g) present after 5 months when applied and incorporated into the soil, and only 20% remaining when soil incorporation was omitted. In a turfgrass management situation, soil incorporation is not commonly practical and was not implemented in this research. Factors - such as temperature, water, light, and fertility - influence morphological characteristics of BG roots. These factors can also influence the soil persistence of some PRE herbicides (Gasper et al., 1994). Treatment affects by pendimethalin did not persist through the end of each sampling period and may be attributed to the degradation of the chemical, though no measurements of chemical persistence were taken. Furthermore, Zimdahl et al. (1984) report that persistence in a silty-clay was much greater than persistence in a sandy-loam. In this study the treatments were applied, and not incorporated, to turfgrass growing in a 90:10 sand, reed-sedge peat mix in which the persistence of a treatment may not be as great as a clay soil (Zimdahl et al., 1984).

Carringer et al. (1975) reported pesticide adsorption is inversely related to water solubility in which compounds with low water solubility are adsorbed greater than compounds with high solubility. Pendimethalin and dithiopyr are characterized by very low water solubility, in comparison to oxadiazon and quinclorac, and strong adsorption to soil colloids (Gasper et al., 1994). The persistence of these products allow for root initiates to contact them well past dormancy break and into the growing season. The degradation of these products relies upon several factors in the soil environment. Pendimethalin was reported to have a half-life of approximately 45 days in a controlled environment and soil temperature of 30°C (Zimdahl et al., 1984). Degradation increased drastically as soil temperature increased from 10°C to 30°C (Bhowmik and Bingham, 1990). The approximate average soil temperature in February in East-Central Mississippi is 10°C, and 30°C exceeds any average soil temperature in the region (Natural Resources Conservation Service – Soil Climate Analysis Network, Mississippi State University site).

Oxadiazon has been reported to have residual herbicide activity of 8 to 15 weeks after application and not to affect rooting of BG at the registered rate (Johnson, 1980; Rao, 2000). The degradation of these products may allow for plant root recovery after critical concentrations of the treatments are reduced. Eight WAT exceeds the number of days (45) that Zimdahl (1984) reported the approximate half-life of pendimethalin in the soil at 30°C, and may explain why 8 WAT pendimethalin reduced TSA but 12 WAT did not negatively affect TSA with respect to the control. Twelve WAT dithiopyr alone had the greatest TSA reductions, but oxadiazon and pendimethalin did not significantly reduce TSA and were comparable to the control. Recovery of plant roots may be more successful in times where concentrations of the treatments are reduced to a level that is not detrimental to roots. Quinclorac and oxadiazon did not significantly reduce TSA with respect to control plants. At the final sampling interval of 2009, quinclorac and pendimethalin treatments did not reduce TSA with respect to the control. Dithiopyr significantly reduced TSA greater than all treatments at this sampling date. The trends in TSA reductions were similar from 2008 to 2009 even though there was a treatment-by-year interaction. In both years of the study, pendimethalin treated plants returned to the control level by 12 and 16 WAT. Dithiopyr treated plants had reductions of 41% and 39% of control, respectively for both years at 16 WAT.

Table 2.10 The effect of chemical treatment on total surface area of both sampling depths summed at 5 sampling intervals in 2009.

	Sampling Interval (WAT ^{x})				
	2	4	8	12	16
Treatment	Total Surface Area^y (cm^2)				
Control	126.1a^z	148.6a	174.0a	155.6ab	178.7a
Dithiopyr	84.6b	98.6a	103.8b	64.0c	70.0c
Oxadiazon	104.6ab	112.4a	141.8a	123.8b	135.8b
Pendimethalin	75.0b	88.4a	96.7b	117.3b	138.1ab
Quinclorac	131.5a	113.4a	166.5a	178.6a	142.4ab

^{x}WAT=weeks after treatment; Treatments applied 12 Mar, 2009.
^{y}Mean surface area (cm^2) of both sampling depths summed together (0-15.2cm).
^{z}Means with the same letter within a column are not significantly different (P=0.05).

Average Root Diameter

In 2008, 8 and 16 WAT were the only sampling dates that showed significant decreases in average root diameter (ARD) (Table 2.11). At 8 WAT, pendimethalin significantly reduced ARD with respect to all treatments except dithiopyr; however, this was the only sampling date that pendimethalin reduced ARD. Reductions of ARD by dithiopyr were only present at 16 WAT. Vaughn and Lehnen (1991) report root tip swelling from applications of PRE herbicides in the dinitroanaline and pyridine families. Pendimethalin has been shown to cause abnormal root growth such as swollen and enlarged epidermal and cortical cells in the roots of ‘Tifgreen’ BG (Dernoeden et al., 1984; Finney, 1991). The results presented herein indicate reductions in ARD by specific treatments but do not dispute abnormal growth or development of the roots.

Table 2.11 The effect of chemical treatment on average root diameter of both sampling depths summed at 5 sampling intervals in 2008.

	Sampling Interval (WAT ^{x})				
	2	4	8	12	16
Treatment	Root Diameter ^{y} (mm)				
Control	0.59203a ^{z}	0.57660a	0.62110a	0.71823a	0.68738a
Dithiopyr	0.53403a	0.57570a	0.57380ab	0.64245a	0.58188b
Oxadiazon	0.60655a	0.57905a	0.60395a	0.73528a	0.65058ab
Pendimethalin	0.59820a	0.54613a	0.50813b	0.63883a	0.67403a
Quinclorac	0.58243a	0.51993a	0.62035a	0.68355a	0.69690a

[x] WAT=weeks after treatment; Treatments applied 15 Mar, 2008.
[y] Mean root diameter (mm) of both sampling depths summed together (0-15.2cm).
[z] Means with the same letter within a column are not significantly different (p=0.05).

In 2009, differences in ARD were observed at every sampling interval except 4 WAT. Dithiopyr reduced ARD the greatest 2 WAT followed by oxadiazon and pendimethalin. Quinclorac was the only treatment not to reduce ARD below control levels 2 WAT, but the effects were not significantly different from oxadiazon and pendimethalin. Eight WAT, the effects of quinclorac, oxadiazon, and pendimethalin were all comparable to control ARD, but dithiopyr significantly reduced ARD greater than control and quinclorac levels. Quinclorac and dithiopyr significantly differed in their effects on ARD 12 WAT, but no treatment differed from control ARD. At the final sampling interval of the second year, only dithiopyr reduced ARD below control levels, and the effects were similar to those of pendimethalin. All other treatments except dithiopyr were comparable to control ARD 16 WAT. The data show a similar trend in year one and year two with respect to ARD. In both years, dithiopyr and pendimethalin both similarly affected ARD 8 WAT and no other treatment reduced ARD below control levels. Likewise, dithiopyr was the only treatment to significantly reduce ARD 16 WAT below control levels both years.

Table 2.12 The effect of chemical treatment on average root diameter of both sampling depths summed at 5 sampling intervals in 2009.

	Sampling Interval (WAT[x])				
	2	4	8	12	16
Treatment	Root Diameter[y] (mm)				
Control	0.50560a[z]	0.52513a	0.57705ab	0.54718ab	0.59200a
Dithiopyr	0.41475c	0.49315a	0.51320c	0.50243b	0.49413b
Oxadiazon	0.44063bc	0.47018a	0.53390bc	0.55225ab	0.57670a
Pendimethalin	0.44293bc	0.52685a	0.54128bc	0.56573ab	0.55020ab
Quinclorac	0.48200ab	0.51130a	0.61313a	0.61255a	0.60723a

[x] WAT=weeks after treatment; Treatments applied 12 Mar, 2009.
[y] Mean root diameter of both sampling depths summed together (0-15.2cm).
[z] Means with the same letter within a column are not significantly different (p=0.05).

The similarities of the trends of treatment effects on root architecture parameters are due to a positive correlation between the parameters across the treatments (Table 2.13). The correlation of root dry mass to root architecture parameters signify an increase in root dry mass will yield an increase in parameters such as length, surface area, and/or diameter. Root length is not the only parameter that influenced root mass, but the strongest positive correlation was found to be between root mass and root length (r=0.626). The weakest relationship was determined to be between ARD and root mass, but ARD is strongly related to the TSA measurement. Both TRL and ARD measurements strongly influence observations on TSA, but according to the data, observations on root mass can be directly, and positively, correlated to observations on all three root parameters. It was hypothesized that a root affected by PRE herbicides would not show a decrease in root mass due to an increase in root diameter from root clubbing. However, the data presented indicate that the affected root systems in fact do reveal a decrease in root mass and as well as the other root architecture parameters.

Table 2.13 The Pearson Correlation Coefficients of root architecture parameters showing the positive relationship between mass and other morphological measurements of root architecture across all treatments in 2008 and 2009.

	Root Architecture Parameters			
	Mass	TRL[x]	TSA[y]	ARD[z]
Mass	1.00	0.626 <.0001	0.611 <.0001	0.146 0.0035
TRL	0.626 <.0001	1.00	0.965 <.0001	0.21 <.0001
TSA	0.611 <.0001	0.965 <.0001	1.00	0.414 <.0001
ARD	0.146 0.0035	0.21 <.0001	0.414 <.0001	1.00

[x] TRL=Total root length
[y] TSA=Total surface area
[z] ARD=Average root diameter
Coefficients with values close to 1.00 represent a stronger positive correlation.

CONCLUSION

In both years of the study, pendimethalin, oxadiazon, and quinclorac did not reduce rooting parameters at 12 WAT or 16 WAT. Dithiopyr treatment effects were observed on all parameters late into the observation period. Dithiopyr significantly reduced all root parameters in both years at 16 WAT. Reductions in TRL, upper root length, TSA, root mass and ARD were observed 16 WAT. Reductions to root architecture parameters late in the growing season may be detrimental to plant survival during drought. July and August are typically the hot, humid, and dry months in central Mississippi. The 16 WAT sampling date was in the first week of July. During the hotter, drier months of the southeastern U.S., it is imperative for a plant to withstand high heat and humidity, and long periods between irrigation. In both years of the study, dithiopyr was the only treatment to significantly reduce rooting parameters at this sampling interval. According to Sullivan et al. (2000), reductions in root parameters are positively correlated to nutrient uptake, so a reduction in root architecture may also hamper the ability for BG roots to grow to depths necessary to withstand drought occurrences without supplemental irrigation.

Treatment effects are greatest by the most treatments 4 and 8 WAT in year one and year two. Pendimethalin, oxadiazon, and dithiopyr all reduce root architecture parameters at these sampling intervals. Minimal affect was observed on the quinclorac treated plants at any sampling interval in both years. As the growing season progresses, root architecture recovery is observed with oxadiazon and pendimethalin treated plants. This can be attributed to better growing conditions for the turfgrass and degradation of treatments in the soil environment. Furthermore, older roots remain unaffected by herbicide treatment due to the growing region of the root not contacting the treatment. To minimize potential root injury, pre-emergent herbicides should be applied after dormancy break and root re-generation has occurred and penetrated the soil >2.5 cm, but prior to weed seed germination. This scenario decreases the most suitable time frame for treatment application for effective control of summer weeds, but is also advantageous to products with both POST and PRE activity such as dithiopyr. More research is needed to better understand the life-cycle of ‘Tifway’ bermudagrass root systems to improve application timing of PRE herbicides to minimize root injury and still be effective in controlling summer annual and grassy weeds.

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CHAPTER III

COMPARISONS OF WATER USE EFFICIENCY OF ‘TIFWAY’ BERMUDAGRASS PLANTS TREATED WITH FOUR PRE-EMERGENT HERBICIDES

ABSTRACT

In the southeastern U.S., drought is a common occurrence. Irrigation must be available to ensure high quality turfgrass. Water use restrictions may be imposed for non-food crops during times of drought. Turfgrass managers use irrigation water from on-site ponds and wells, or municipal water. In drought situations, irrigation water may not be available for the turfgrass manager if restrictions occur. Without water, the turf will be negatively affected beyond acceptable criteria of high quality turfgrasses. When using herbicides to control weeds during the growing season, water use is generally not a fore-thought in the outcome of the application. Pre-emergent (PRE) herbicides have been shown to negatively affect turfgrass roots. Research was conducted simultaneously at Mississippi State University and Louisiana State University to determine the effect of PRE herbicides on evapo-transpiration water loss (ETWL) of ‘Tifway’ bermudagrass (Cynodon dactylon X C. transvaalensis Burtt-Davy) grown on a sand/peat mix. Plants were treated with dithiopyr, oxadiazon, pendimethalin, and quinclorac in March 2009. Herbicide treated plants were subjected to deficit irrigation (DI) and zero irrigation (ZI) for 28 days in a greenhouse at 8 and 12 weeks after herbicide treatment (WAT). Reduced

ETWL was observed in 8 WAT plants that were treated with pendimethalin and dithiopyr, but no PRE treatment significantly or consistently affected ETWL 12 WAT. Visual quality ratings revealed similar trends in turfgrass quality decline across treatments, but differences were observed between the two locations.

INTRODUCTION

Irrigation water is not generally an issue in turfgrass management until it becomes limited or un-available. Irrigation water availability is becoming an increasing concern for landscapes in urbanized areas where restrictions are often imposed (Marcum, et al. 1995). McCarty (2005) sites water as the primary input required for growth and survival of all turfgrasses. In the southeastern U.S., irrigation water is generally plentiful for most of the year. In Central Mississippi, average rainfall is over 50 inches per year. Irrigation availability during the rainy season is not of major concern, but when the summer months bring less rain, irrigation water becomes a primary concern to any turfgrass manager.

Turfgrasses can be grown on a variety of mediums, each with their own independent water-holding and drainage capabilities. Adequate soil moisture is required to maintain plant growth, quality and density (Taliaferro, 2003; Baldwin et al., 2006). Some common growing media for turf in the southeastern U.S. include native soils – which can range from loams to sandy alluvial soils to clays – sand-capped native soils, and sand-peat mixes. High clay, native soils have greater amounts of micropores that allow for slow movement of water and gases, and high sand soils contain more macropores that allow for rapid and free movement of water through the soil profile (Brady and Weil, 1996). It is important for the turf manager to have an understanding of the characteristics of the soil media and the management practices involved with growing turf on that media. Irrigation management could be the most important practice implemented to maintain high quality turfgrasses because water is considered the most precious and limited resource (Qian and Engelke, 1999). Insufficient rainfall is a common stress that leads to the decline and loss of turfgrass. In most regions of the U.S., high maintenance turfgrasses cannot be adequately maintained without supplemental irrigation through the growing season (Qian and Engelke, 1999). Reducing irrigation frequency and allowing for water percolation into the soil profile produces larger and deeper root systems and higher quality turfgrasses (Qian and Engelke, 1999; Baldwin et al., 2006). Increasing the interval between irrigation cycles also conditions the turfgrass for periods of lower water availability (Jordan et al., 2005). A healthy root system will allow plants to combat times of water stress by utilizing water held in the soil at greater depths. Differences in root architecture parameters may allow for water loss observations between plants with unaffected roots and roots that have reduced parameters of root architecture (mass, length, surface area, and/or diameter). It has been shown that the use of some PRE herbicides negatively affect the root architecture of hybrid bermudagrass (Cynodon dactylon X C. transvaalensis Burtt-Davy) - a widely used turfgrass in the southeastern U.S (Rossi, 1992; Fishel and Coats, 1994).

Pre-emergent herbicides are applied in the spring to control summer weeds and the application timing coincides with root re-generation of warm-season turfgrasses (Engel and Illnicki, 1969). Although research is limited on the effect of PREs on water uptake, damages incurred on the roots of turfgrasses are reported to be positively correlated to nitrogen uptake rate (Sullivan et al., 2000). According to Barber (1961), nitrogen enters the plant in the form of ammonium (NH_4□) and nitrate (NO_3□) via mass flow. It stands to reason a reduction in the nitrogen uptake rate due to reductions in root architecture parameters may be correlated to a reduction in water uptake abilities of the root or a reduction in the overall root numbers intercepting water and nutrients. The main function of the plant root is to intercept water and nutrients (Beard, 1973; Baldwin, 2006). Bowman et al. (1998) reported nitrate leaching was 38% on a short root genome of creeping bentgrass (Agrostis stolonifera L. Huds) compared to 18% on a deep root genome. Decreasing the number or the ability of these roots to intercept these vital resources will reduce the quality and health of turfgrasses.

Evapo-transpiration is the combination of the amount of water loss due to evaporation from the plant and soil. Evapo-transpiration rates can be affected by wind velocity, relative humidity, air temperature, soil temperature, and turfgrass species (Kim and Beard, 1988). Monitoring ET rates daily is important in turfgrass management because the plants contain 75-85% water by weight and wilting occurs with just a 10% reduction in water content (Beard, 1966; Beard 1973; Baldwin et al., 2006). Plants that are able to obtain and use available water more efficiently will have greater evapo-transpiration water loss (ETWL) than plants that obtain and use water less efficiently. Monitoring ET losses may be an effective practice to observe differences in soil water use and root water uptake.

It is advantageous to encourage a deep, healthy root system to avoid drought stress in turfgrasses (Qian and Engelke, 1999; Baldwin et al., 2006).Some PRE's have been shown to negatively affect root architecture parameters, including root length and surface area (Fishel and Coats, 1994; Sullivan, 2000).

The objective of this research was to determine if roots that have been negatively affected by PRE herbicides have a decreased ability to utilize water and sustain plants during times of decreased water availability.

MATERIALS AND METHODS

Research was conducted simultaneously at Mississippi State University's R.R. Foil Plant Science Research Facility in Starkville, MS, and at Louisiana State University Agriculture Center Burden Research Farm in Baton Rouge, LA. Each experiment was conducted in the same manner and the same evaluations taken at each location. Turf plots at both locations were fully established 'Tifway' bermudagrass growing on a 90:10, sand and reed-sedge peat mix grown in full sun. A complete fertilizer (13N-5.7P-10.8K) was added to the entire research area on the day of herbicide treatment at a rate of 48.79 kg N ha^{-1}. Five 1.8 X 3.9m plots were randomly assigned herbicide treatments. The four PRE treatments – dithiopyr 1-EC (Dow AgroSciences, Dimension^{tm}) 0.318 kg ai ha^{-1}, oxadiazon 2-G (Bayer, Ronstar^{tm}) 4.39 kg ai ha^{-1}, pendimethalin 3.8-CS (BASF, Pendulum^{tm}) 3.273 kg ai ha^{-1}, and quinclorac 75-DF (BASF, Drive^{tm}) 2.242 kg ai ha^{-1} – were applied at the labeled maximum single application rate for each product. Treatments were applied 12 March 2009, at the MSU location and 19 March 2009 at the LSU location. Treatments were applied at a later date at the LSU location due to prolonged inclement weather and structural damages at the research site. All herbicides were applied simultaneously at the respective location and irrigated for ten minutes per label directions. After treatment, plants were maintained at 1.5 cm with a reel mower three times per week and the clippings returned to the turf. Four weeks after treatment (WAT)

48.78 kg Nitrogen (N) ha^{-1} in the form of NH_4NO_3 (34-0-0) was applied and irrigated. Six samples from each plot were randomly harvested 5 WAT using a standard cup-cutter and randomly placed into 10.1 cm X 30.5cm polyvinylchloride (PVC) lysimeters. Lysimeters were constructed of 10.1cm PVC drain pipe and flat-bottomed caps with six 0.5cm holes drilled in the cap for drainage. After randomly placing each plug into a lysimeter, a 90:10, sand to reed-sedge peat mix was added from the bottom of the lysimeter and compacted until full. Different sand was used at each location, so a particle size analysis was performed on sand samples from each location (Table 3.1). Whatman^{tm} #50 (Whatman International, Ltd., Maidstone, England) filter paper was placed on the bottom of the lysimeter and the cap forced on. Three replications of each herbicide treatment were subjected to two irrigation schedules.

All plants were placed in a greenhouse environment for 21 days prior to initiation of irrigation treatments. Plants were subjected to 23-30°C day and night temperatures for the 8 WAT evaluations, and 24-33°C day and night temperature at 12 WAT. A temporary failure with the cooling system at the MSU location allowed maximum day temperatures to reach up to 46°C for no greater than 3d. The plants were clipped with reciprocating hand shears twice per week to a height of 1.5cm and the clippings removed from the turf canopy. The plants were monitored in a greenhouse situation to better control environmental conditions and precisely measure the amount of irrigation applied to each lysimeter. The temperature within the greenhouses at both locations were set to mimic the average day and night temperatures for 8 WAT (May 15) and 12 WAT (June 15) for the MSU location.

Table 3.1 The sand particle size analysis of the two root zone media at both locations.

Sand Particle Size Analysis g/100g		
Size Fraction (mm)	MSU	LSU
Fine Gravel (<4.00)	0.4	0.0
Very Coarse Sand (2.0–1.0)	2.3	0.0
Coarse Sand (1.0-0.5)	12.9	11.0
Medium Sand (0.5-0.25)	61.7	81.0
Fine Sand (0.25-0.15)	18.5	7.0
Very Fine Sand (0.15-0.5)	1.2	< 1.0
Silt	2.0	< 1.0
Clay	1.0	<1.0

The weight of each lysimeter at field capacity (FC) was determined by taking an average of 3 weights after saturating and draining the lysimeter. Each lysimeter was placed in a 20cm deep tub and slowly irrigated from the top until water ceased to percolate. The lysimeter remained in standing water in the tub for 24 hours and was removed and allowed to drain for 16 hours and dripping had ceased and were then weighed. This process was repeated 3 times and the average of the three FC readings recorded. The final FC observation was conducted so that the beginning of irrigation treatment would begin with all lysimeters at FC.

The herbicide treatments were exposed to deficit irrigation (DI), and zero irrigation (ZI) regimes. All lysimeters were weighed every-other day at 1300 hours to the nearest gram (g) beginning 2 days after initiation of water treatment (DAIT). Weighing each pot determined the amount of ET water missing from each lysimeter and allowed for determination of differences in water use between the treatments. The methods followed are a modification of the methods used by Baldwin et al. (2006), in which lysimeters were weighed to determine the amount of ETWL at various irrigation intervals. Plants under DI received 60% of ET water returned for 2, 4, and 6 DAIT, then 30% of ET water returned for 8, 10, and 12 DAIT, and then zero irrigation for the remainder (16d) of the evaluation period for a total of 28d. The ZI schedule provided no irrigation from the commencement of evaluation until the end of the evaluation period or the death of the plant (>90% brown canopy), whichever came first.

Both irrigation treatments were observed for differences in total overall water use and for differences in percentage ETWL per day of each herbicide treatment. Visual quality ratings were recorded by combining the quality of the color, density, and turgor of each individual plant on a scale of 1 to 9, with one being completely brown and nine being lush and green – similar to the National Turfgrass Evaluation Program. A rating <5 was considered un-acceptable turf quality.

The experimental design was a completely randomized design with three replications of each treatment. Control lysimeters received the same water treatment as the lysimeters with PRE treated plants, but received no PRE application prior to commencement of water treatment. Observations of ETWL were recorded every-other day at 1300 hrs, and the data separated by the general linear model procedure of Statistical Analysis Software (SAS, Cary, NC) at the $p=0.05$ level of significance using Fisher's Protected LSD.

RESULTS AND DISCUSSION

Analysis of the data showed significant differences ($p=0.05$) of ETWL at the two locations, but both locations revealed similar and significant differences between PRE treatments evaluated (Table 3.2 and Table 3.3). No location x PRE interaction was determined for either observation period, so the data are pooled.

Table 3.2 The fixed effects model of the analysis of variance (p=0.05) for the mean total ET water loss at two locations 8 WAT[x] in 2009.

The Fixed Effects Analysis of Variance				
Effect	Num/Df	Den/Df	F-Value	Pr > F
Location	1	4	161.87	0.0002
PRE	4	36	4.78	0.0034
Loc x PRE	4	36	1.62	0.1915
Water Trt[y]	1	36	140.43	<0.0001
Loc x Trt	1	36	373.57	<0.0001
PRE x Trt	4	36	0.44	0.7797
Loc x PRE x Trt	4	36	1.06	0.3921

[x] WAT=weeks after treatment; Treatments applied 12 Mar (MSU) and 19 Mar, 2009 (LSU)

[y] Trt= Water treatment.

Means separated at the 0.05 level of significance.

Table 3.3 The fixed effects model of the analysis of variance for the mean total ET water loss at two locations 12 WAT[x] in 2009.

The Fixed Effects Analysis of Variance				
Effect	Num/Df	Den/Df	F-Value	Pr > F
Location	1	4	26.18	0.0069
PRE	4	36	5.63	0.0013
Loc x PRE	4	36	0.72	0.5822
Water Trt[y]	1	36	6.94	0.0124
Loc x Trt	1	36	54.23	<0.0001
PRE x Trt	4	36	1.63	0.1891
Loc x PRE x Trt	4	36	1.24	0.3098

[x] WAT=Weeks after treatment; Treatments applied 12 Mar, (MSU) and 19 Mar, 2009 (LSU).

[y] Trt=water treatment.

Means separated at the 0.05 level of significance.

The DI treatment at LSU resulted in twice the amount of ETWL at the MSU location at 8 WAT, but no differences were observed 12 WAT with this treatment (Table 3.4). The ZI treatment revealed greater ETWL at the MSU location for both sampling intervals. Plants maintained under DI lost significantly more ET water than did the ZI treastment at LSU. A greater amount of water was available for plant use and evaporation due to the irrigation applied to the plants during the first few days of observation. The same trend is not observed at the MSU location. Plants maintained under DI treatment had less ETWL at 8 and 12 WAT at MSU. The discrepancy in ETWL between treatments at the two locations may be attributed to milder temperatures at MSU and slight differences in the water-holding capabilities of the two sands at the two sites. Lower temperatures may have allowed for slower rates of ETWL and lessened the rapid effects of stress incurred on plants under water and heat stress (Beard, 1973).

Table 3.4 Mean total ET water loss of the two water treatments at both locations at 8 and 12 weeks after treatment in 2009.

	Total ET water loss (g)			
	8 (WAT[1])		12 (WAT)	
Water treatment	MSU	LSU	MSU	LSU
Deficit Irrigation	536.0	1090.1	764.5	785.6
Zero Irrigation	653.7	599.5	817.3	673.9
LSD (0.05)	36.1	36.1	23.5	23.5

[1] WAT =Weeks after treatment; Treatments applied12 Mar, (MSU) and 19 Mar, 2009 (LSU).

Treatments applied 12 Mar (MSU), and 19 Mar (LSU), 2009.

The differences in ETWL between the locations may be influenced by the timing of the PRE application to plants in the field. Treatments were applied to plants at the

LSU location (19 Mar, 2009) that were estimated to be >75% green in comparison to <25% green at the MSU location (12 Mar, 2009). The LSU site is within the boundaries of USDA hardiness zone 8b, in contrast to the MSU location being in zone 7b. High and low air temperatures at PRE treatment application were 19.5/7.8°C at MSU compared to 27.2/11.7°C at LSU. The geographical differences play a vital role in the discrepancy of the growth stage of the BG at the two sites. Observations on ETWL were made in a controlled environment, but the differences in external temperatures and the variation between the two root zone media may have influenced the results.

According to Beard and DiPaola (1978), annual root re-generation occurs approximately one week after spring green-up. The timing of the PRE applications varied greatly with respect to spring green-up at the different locations. Recommendations for PRE application at the two locations vary due to the geographical and climatic differences. It is common practice for turf managers in USDA hardiness zone 8b to apply PRE treatments on or about 15 February each year when soil temperatures near 10°C. This is estimated to occur approximately 2 to 4 weeks sooner than in zone 7b. Data from the previous chapter, and other research (Beard and DiPaola, 1978; Fishel and Coats, 1994), suggest PRE application timing should allow for root penetration beyond the upper few millimeters of the soil prior to treatment. In accordance with Beard and DiPaola (1978) PRE application should occur after approximately 10d of visible spring green-up to prevent root injury, and this did not occur at the MSU location. The discrepancy in the timing of PRE application allowed for an uncompromised, healthy root system at the LSU location and a greater chance of herbicide influence on the root system at the MSU location. Waiting later in the growing season to apply PRE's may allow for weed germination and lack of acceptable control of some herbicides. It may be more advantageous to use products, such as dithiopyr, that control weeds PRE and post-emergence.

Differences in ETWL due to PRE treatments were observed at both 8 and 12 WAT at both locations (Table 3.5). Dithiopyr and pendimethalin significantly reduced mean total ETWL greater than any other treatment 8 WAT. Quinclorac also reduced ETWL in comparison to the control, but the effects were not as severe as pendimethalin or dithiopyr. A reduction in ETWL in comparison to the control may signify a compromised root system that is unable to obtain water as efficiently as an uncompromised root system. At 12 WAT, pendimethalin treated plants had the greatest increase of ETWL from 8 WAT. This signifies there was likely significant root recovery from possible prior injury. On a percent-of-control basis, pendimethalin treated plants reduced mean ETWL >12% with respect to the control 8 WAT, but that amount reduced to <4% 12 WAT. In the previous chapter, negative treatment effects of pendimethalin and dithiopyr were most severe at 8 WAT. The least treatment effects were observed at 12 and 16 WAT. Significant effects were observed at 12 WAT although the trend in the data tends to indicate possible recovery with pendimethalin. Water loss from each lysimeter indicates that either water is being taken up by the plant or evaporated from the plant-soil interface. Plants with roots affected by herbicide treatments may not have the architectural characteristics-specifically length- necessary to obtain water held at greater depths in the profile of the lysimeter, thus, less water was lost.

Table 3.5 Mean total ET water loss of the two water treatments across both locations at 8 and 12 WAT[1] in 2009.

	8 (WAT[1])	12 (WAT)
Herbicide treatment	-------------------Water loss (g)	------------------
Control	770.2a	791.3a
Dithiopyr	689.8cd	722.5c
Oxadiazon	743.0ab	787.2a
Pendimethalin	675.8d	760.3b
Quinclorac	720.4bc	740.3bc
LSD (0.05)	37.6	23.5

[1] WAT =Weeks after treatment; Treatments applied 12 Mar, (MSU) and 19 Mar, 2009 (LSU).

Means with the same letter within a column are not significantly different (p=0.05)

A reduction in irrigation frequency encourages plants to form larger and deeper root systems which in turn help to increase turfgrass quality Qian et al. (1997). However, as stated in the previous chapter, a root system of a plant that has been compromised by a PRE herbicide may not be able to generate as deep a root system to help combat water stress during times of reduced irrigation. Nutrient use evaluations were not observed in this research, but it is important to note that prior research has reported a positive correlation between root architecture parameters - such as length and surface area - and nitrogen uptake capabilities (Sullivan et al., 2000). Further, Bowman et al. (1998) reported a greater amount of nitrate leaching in a short-root genome of creeping bentgrass (Agrostis stolonifera Huds.) than a long-root genome. The previous reports of nutrient interception may be correlated to water interception and uptake because nitrate enters the plant root via mass flow (Barber, 1961). Roots that are unaffected by PRE herbicide treatments are allowed to grow and develop in a normal manner into the soil profile. Greater root length and surface area of healthier root systems will lead to more efficient uptake of nitrate, and possibly even water (Barber, 1961; Bowman et al., 1998; Sullivan et al., 2000). The healthy roots should feasibly reach depths necessary to absorb water held deeper in the profile and be able to sustain the quality of the turfgrass in times of low water potential (Jordan et al., 2005). Root systems that have been negatively altered due to PRE herbicide treatment may not be able to intercept as great of an amount of deep water in the soil due to the shortening of the root system. The data presented show plants 8 WAT with un-affected root systems were able to obtain more water from the lysimeters in comparison to dithiopyr and pendimethalin (Table 3.5). Likewise, 12 WAT the data show greater amounts of ETWL from pendimethalin treated plants suggesting a healthier root system than the previous observation period.

Location x PRE and water treatment x PRE interaction were not significant, but differences (p=0.05) were observed between the two locations (Table 3.6). The absence of PRE effect on the per-day basis suggests the differences in temperature at the two locations in combination with differences in the root zone media had a larger effect on ETWL than did the PRE herbicides evaluated. Evaluations on per-day basis may be of less consequence than observations on total ETWL. The amount of ETWL per day was greater at the LSU location at both observation periods (Table 3.8). Short-term irrigation deficits are encouraged in turfgrass management programs (Huang and Fry, 1998), but long-term water deficits are more detrimental to BG (Baldwin et al., 2006) and may exaggerate subtle effects from PRE treatments.

Table 3.6 The analysis of variance for the mean ET water loss per day at two locations 8 WAT[x] in 2009.

		Analysis of Variance (p=0.05)			
Effect	Df	Sum of Squares	Mean Square	F-Value	Pr > F
Location	1	3004.19	3004.19	446.29	<0.0001
PRE	4	39.91	9.98	1.48	0.2280
Loc x PRE	4	7.65	1.91	0.28	0.8864
Water Trt[y]	1	31.02	31.02	4.61	0.0386
Loc x Trt	1	454.08	454.08	67.46	<0.0001
PRE x Trt	4	59.28	18.63	2.20	0.0884
Loc x PRE x Trt	4	74.53	10.93	2.77	0.0419

[x] WAT=weeks after treatment; Treatments applied 12 Mar, (MSU) and 19 Mar, 2009 (LSU).

[y] Trt=water treatment.

Means separated at the p=0.05 level of significance.

Table 3.7 The analysis of variance for the mean ET water loss per day at two locations 12 WAT[x] in 2009.

		Analysis of Variance (p=0.05)			
Effect	Df	Sum of Squares	Mean Square	F-Value	Pr > F
Location	1	118.16	118.16	13.07	0.0009
PRE	4	88.58	22.15	2.45	0.0637
Loc x PRE	4	22.58	5.65	0.62	0.6480
Water Trt[y]	1	320.58	320.54	35.45	<0.0001
Loc x Trt	1	17.54	17.54	1.94	0.1722
PRE x Trt	4	57.93	14.48	1.60	0.1949
Loc x PRE x Trt	4	33.45	8.36	0.92	0.4602

[x] WAT=weeks after treatment; Treatments applied 12 Mar, (MSU) and 19 Mar, 2009 (LSU).

[y] Trt=water treatment.

Means separated at the p=0.05 level of significance.

Table 3.8 Mean ET water loss per day across the two water treatments at either location 8 and 12 weeks after treatment in 2009.

	ET Water Loss (g)	
Location	8 (WAT[1])	12 (WAT)
MSU	21.3b	29.0b
LSU	35.5a	31.8a
LSD (0.05)	1.36	1.57

[1] WAT =Weeks after treatment; Treatments applied 12 Mar, (MSU) and 19 Mar, 2009 (LSU).

Means with the same letter within a column are not significantly different (p=0.05)

The percent of ETWL per day was significantly different between locations, and no specific trends of PRE effects were observed at either of the two sites (Table 3.9).The differences between the two locations can be attributed to factors such as PRE application timing, climatic differences, and variability in the root zone media at the two sites.

Table 3.9 The mean percent of ET water loss per day of the two water treatments at both locations 8 and 12 weeks after treatment in 2009.

	Percent ET Water loss							
	8 WAT[1]				12 WAT			
	MSU		LSU		MSU		LSU	
Treatment	DI[2]	ZI[3]	DI	ZI	DI	ZI	DI	ZI
Control	2.34a	2.84a	3.9ab	3.33a	3.26ab	3.4b	3.56a	3.47b
Dithiopyr	2.12ab	2.54a	3.82b	3.59a	2.89b	3.44b	3.22b	4.32a
Oxadiazon	2.24ab	2.74a	4.17ab	3.34a	3.24ab	3.54b	3.23b	3.99ab
Pendimethalin	2.07b	2.54a	3.64b	3.27a	3.42a	3.96a	3.59a	4.17ab
Quinclorac	2.17ab	2.56a	4.42a	2.78b	2.99b	3.29b	3.39ab	3.65ab
LSD	0.25	0.35	0.59	0.42	0.37	0.36	0.29	0.81

[1] WAT=Weeks After Herbicide Treatment

[2] DI=Deficit Irrigation water treatment

[3] ZI=Zero Irrigation water treatment

Means with the same letter within a column are not significantly different (p=0.05)

Visual Quality Ratings

The reported effects of PRE treatments on ETWL were not always significant, although trends were evident in the data. Dithiopyr and pendimethalin significantly affected mean total ETWL greater than other treatments 8 WAT. A negative effect on ETWL suggests less efficient interception and use of plant available water. Nearly 75-85% of the weight of turfgrass plants is water, and the plant will begin to wilt with only a 10% decrease in water content (Beard, 1966; Beard 1973; Baldwin, 2006). The observations on visual quality should depict any negative changes in water uptake of PRE treated plants. At 8 WAT, the DI treatment at MSU declines in quality in a similar trend amongst PRE until 14 days after initiation of water treatment (DAIT) (Figure 3.1). The plants at the LSU location did not follow the same trend in visual quality reductions. No significant reductions in turf quality were evident at the LSU location until 24 days after initiation of water treatment (DAIT) by dithiopyr (Figure 3.2). Reductions in visual quality, although not always significant, at the MSU location may be due to PRE effects on the root architecture and the inability for roots to uptake water at deeper depths. Temperatures were not as warm at MSU and the previous data reported show nearly one-half of the ET water loss than at LSU, but reductions in visual quality were evident at this site. At the commencement of water treatment for the 8 WAT observation period, the high/low temperatures were 22.8/16.7°C at MSU in comparison to 31.7/21.1°C at LSU. The warmer temperatures at LSU, in combination with a deeper, healthier root system may have allowed for greater ETWL. However, the less affected root systems at the LSU site may have attributed to a slower decrease in visual quality ratings than MSU. No treatment decreased visual quality ratings below 5 at either location over the observation period.

Turf quality reductions were evident between the MSU and LSU locations for the ZI treatment at 8 WAT (Figure 3.3 and Figure 3.4). Although both locations had reductions in turf quality across PRE treatments, the plants at the LSU location had a much more rapid decrease in turf quality in comparison to the MSU location. The more rapid decrease may be attributed to the warmer temperatures at LSU. Turf plants received un-acceptable (<5) ratings approximately 24 DAIT at the MSU location, but due to the higher temperatures, and more rapid water loss, only 12 DAIT yield a reduction in quality below acceptable standards at the LSU location. The more rapid decline at the more southern location can be attributed to differences in climate, but it is hypothesized that the differences in the PRE application timing had an effect, also. According to Beard and DiPaola (1978), annual root re-generation of BG roots occurs approximately one week following spring green up. Warmer mean temperatures at the initiation of treatment at the LSU location allowed for more advanced stages of spring green up than the MSU location. The turfgrass at the LSU location was approximately 75% green when treated with PRE treatments, and plants at the MSU location were approximately 25% green.

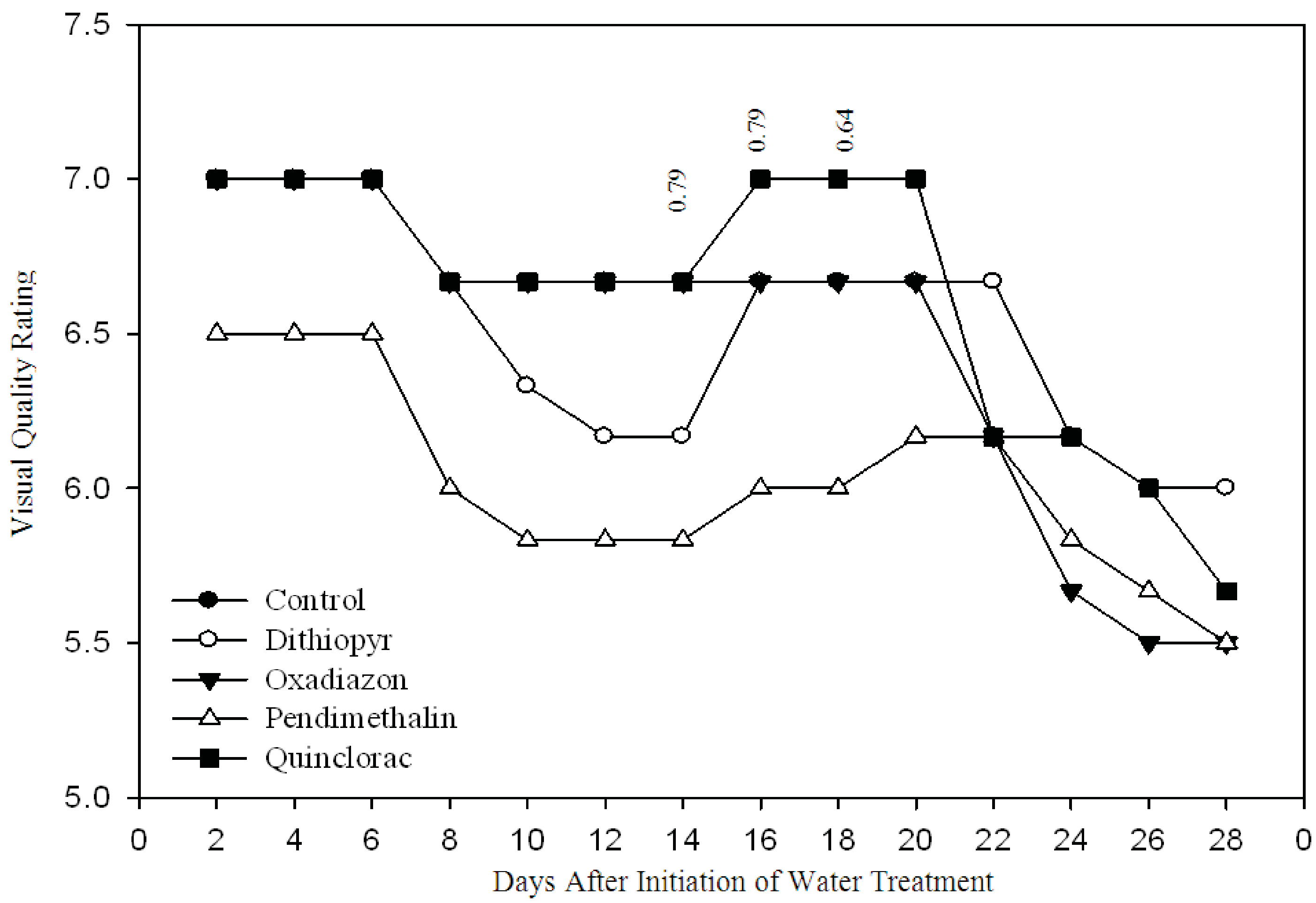

Figure 3.1 Visual quality ratings of the deficit irrigation treatment at 8 weeks after herbicide application at MSU in 2009. Significant differences (p=0.05) are represented by LSD values at the corresponding sampling interval. If no LSD values are present, then no significant differences were observed at the sampling interval.

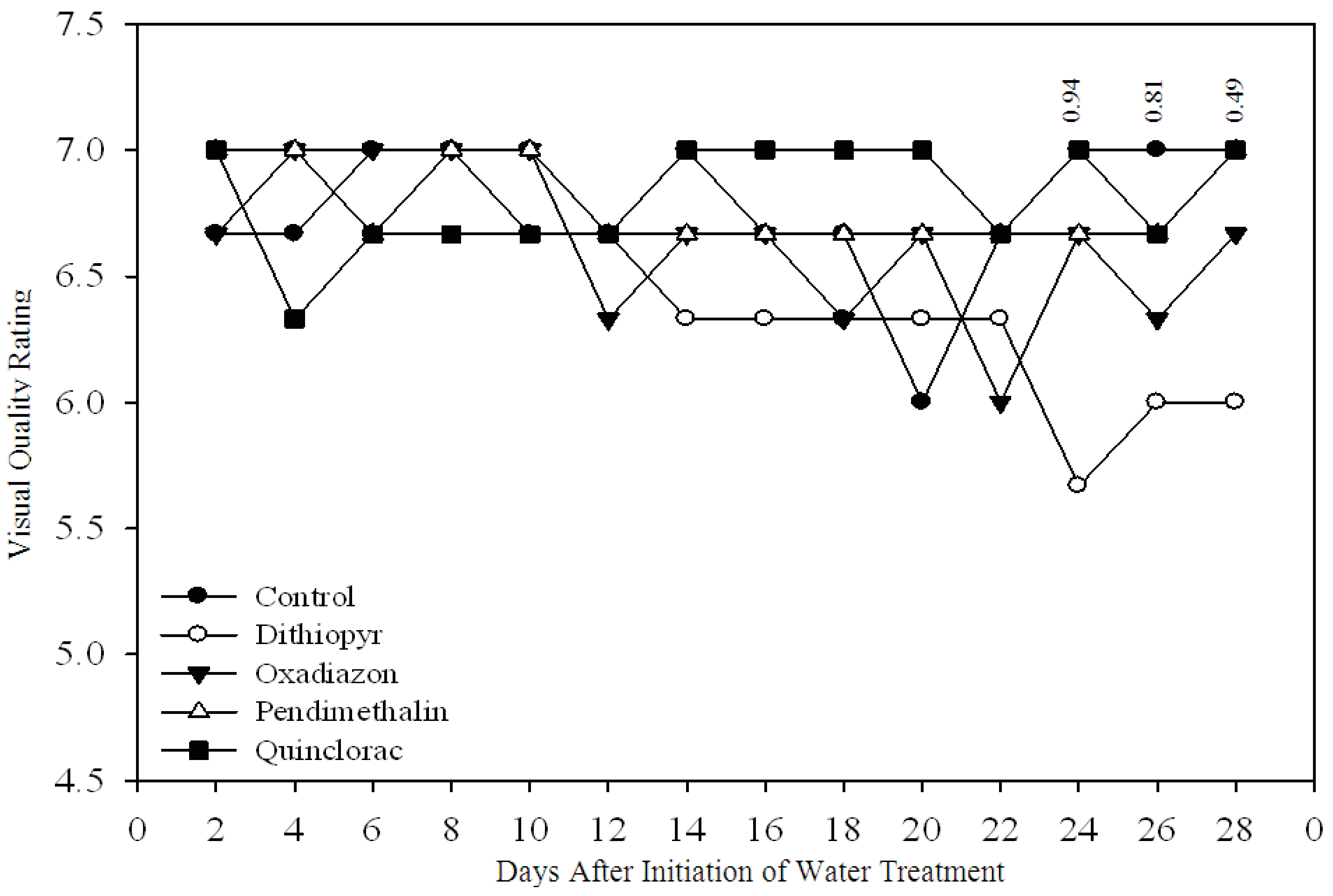

Figure 3.2 Visual quality ratings of the deficit irrigation treatment at 8 weeks after herbicide application at LSU in 2009. Significant differences (p=0.05) are represented by LSD values at the corresponding sampling interval. If no LSD values are present, then no significant differences were observed at the sampling interval.

According to Beard and DiPaola (1978) a new root system may have already begun forming at the time of the PRE application at LSU. The advancement of the meristematic region of the root past the top few millimeters of soil where the PRE treatments were present prevented herbicide injury and allowed for normal growth and development of a healthy root system (Fishel and Coats, 1994). The healthy root system, in combination with warmer temperatures, was able to obtain and use the water held at deeper depths more rapidly versus the compromised root system. The plants at MSU did not begin turf quality decline as quickly because the milder temperatures did not expedite ET water loss like the warmer temperatures at LSU. If ET water loss is slower due to milder temperatures, plant available water may be present in the lysimeter for a greater amount of time. The plants at MSU were not exposed to as great of temperatures as the plants at LSU and therefore did not lose ET water as rapidly resulting in a slower decline in turf quality.

Pendimethalin reduced turf quality ratings quickly at the MSU location with respect to the control and other treatments under ZI treatment, but the effects were short-lived (Figure 3.3). Significant reductions in turf quality were observed at 8, 12, and 16 DAIT, but no other sampling interval yielded a significant reduction in turf quality. At 20 DAIT, no differences in the trend of quality reduction were observed due to any PRE treatment at MSU. Pendimethalin, as well as dithiopyr, reduced visual quality ratings from other treatments at LSU (Figure 3.4). The rapid reduction in quality ratings can be ttributed to the warmer temperatures increasing the amount of ETWL between sampling intervals and a healthier root system due to the absence of PRE treatment effects.

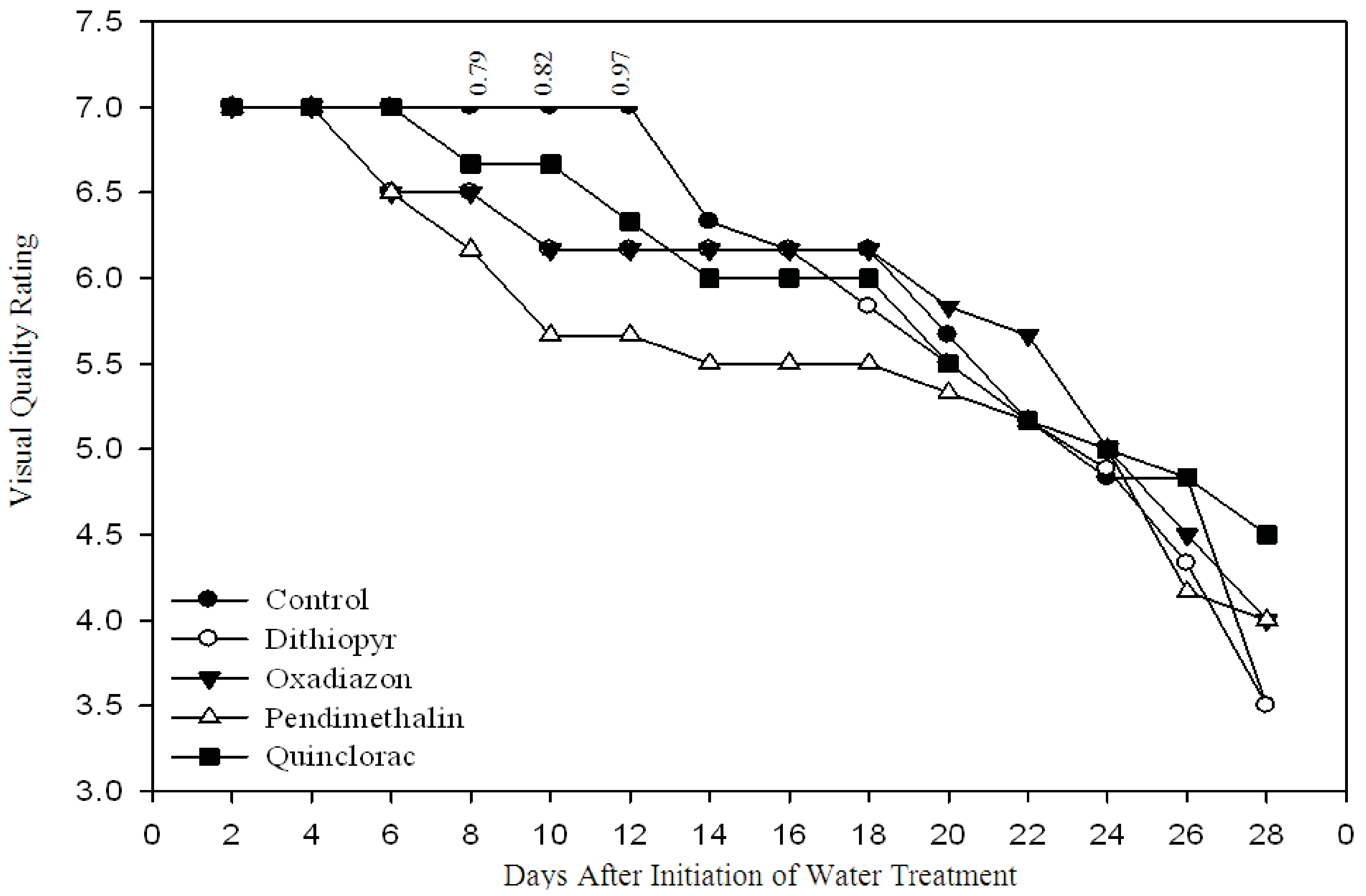

Figure 3.3 Visual quality ratings of the zero irrigation treatment at 8 weeks after herbicide application at MSU in 2009. Significant differences ($p=0.05$) are represented by LSD values at the corresponding sampling interval. If no LSD values are present, then no significant differences were observed at the sampling interval.

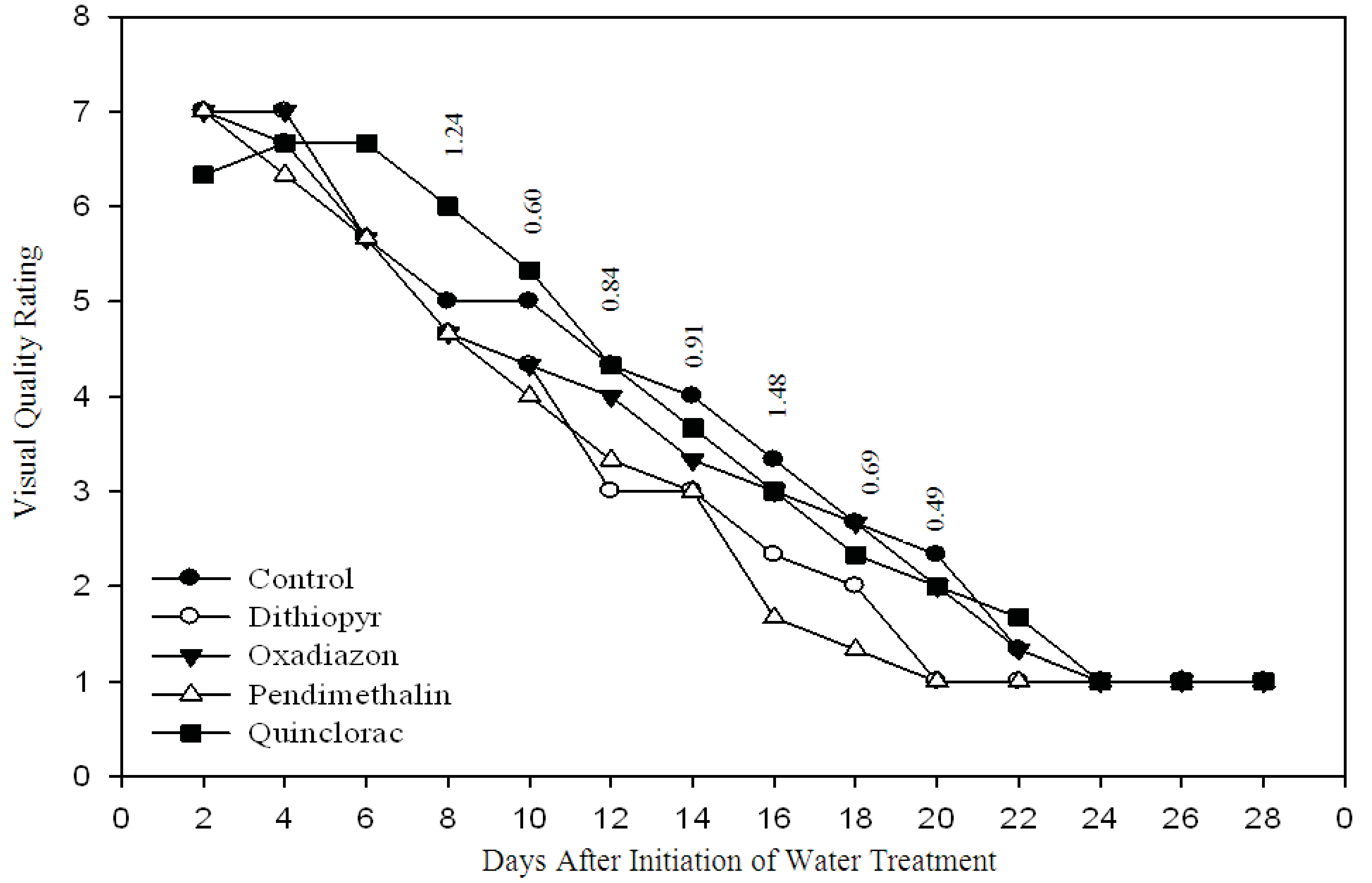

Figure 3.4 Visual quality ratings of the zero irrigation treatment at 8 weeks after herbicide application at LSU in 2009. Significant differences (p=0.05) are represented by LSD values at the corresponding sampling interval. If no LSD values are present, then no significant differences were observed at the sampling interval.

The DI treatment at the 12 WAT observation period affected turf quality at the MSU location similarly to plants at the LSU location, although subtle differences were observed between the two (Figure 3.5 and Figure 3.6). Plants at both locations maintained acceptable visual quality (>5) ratings until 20 DAIT at the MSU location and 22 DAIT at the LSU location. In general, the trend of visual quality reduction is similar between PRE treatments evaluated, although some statistical differences were observed at various sampling intervals. The high/low temperatures at the initiation of water treatment for the 12 WAT observation period at MSU were 31.7/18.9°C and 33.3/21.7°C at LSU. The general trend is similar at both locations due to more comparable environmental conditions and the amount of time lapsed from the application of PRE treatments in the field. Slight reductions in visual quality were observed early at the LSU location, but the effects were not as severe and rapid as the effects 8 WAT. Further, the previous chapter showed significant recovery of root length by most treatments 12 WAT. The comparable visual quality ratings at both locations tend to agree with the findings of the previous chapter. Healthy and deep root systems were able to maintain acceptable plant quality well into the observation period until plant available water was depleted. A negatively affected root system would not be able to maintain as great of plant quality without the supplemental irrigation that was added following the initiation of DI treatment. Although not significant, the sharpest reduction in visual quality following the final DI water added occurred on quinclorac treated plants. The plants were able to utilize the DI water added, but also obtained water held at greater depths in the lysimeter and depleted the water source more rapidly than the other treatments.

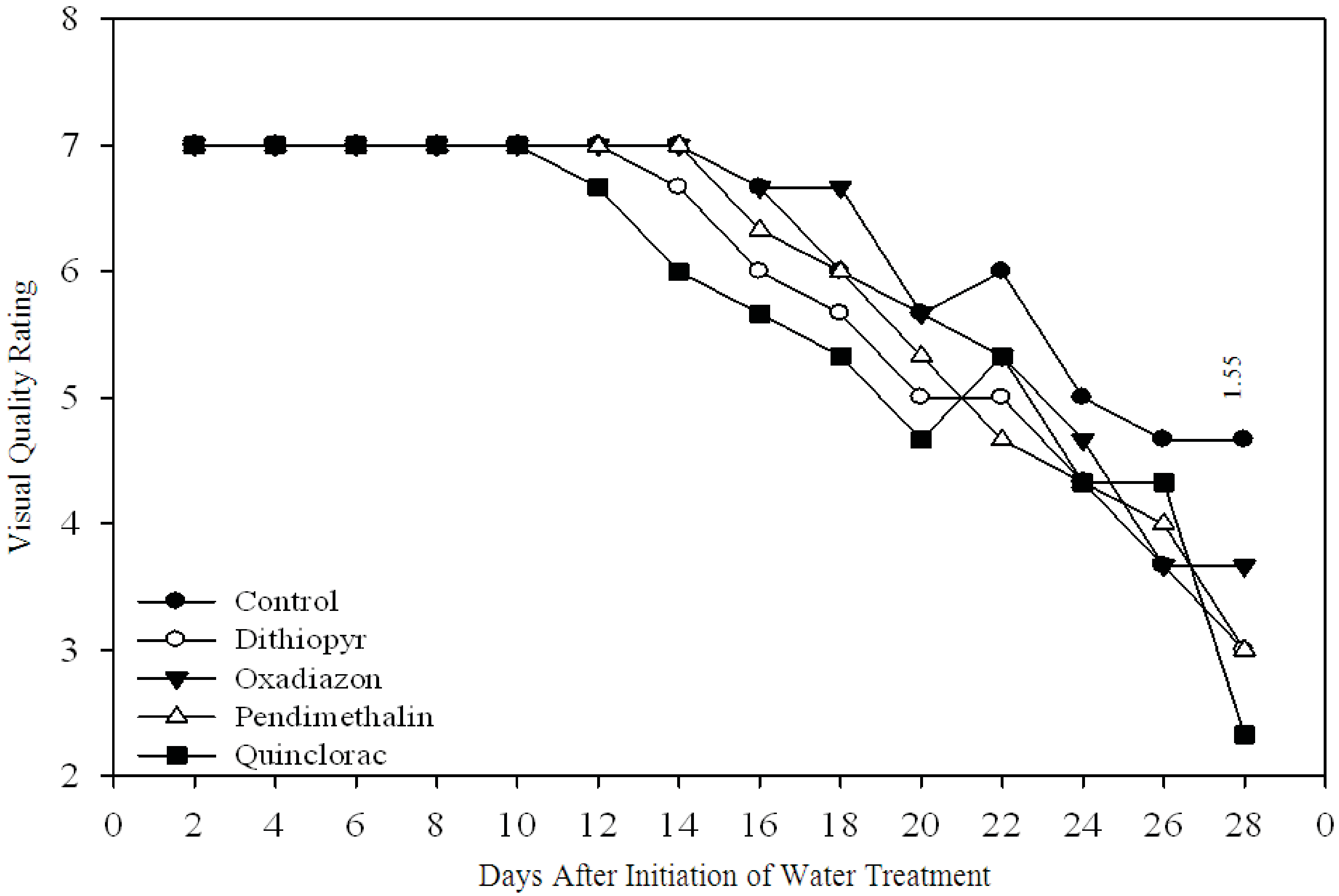

Figure 3.5 Visual quality ratings of the deficit irrigation treatment at 12 weeks after herbicide application at MSU in 2009. Significant differences (p=0.05) are represented by LSD values at the corresponding sampling interval. If no LSD values are present, then no significant differences were observed at the sampling interval.

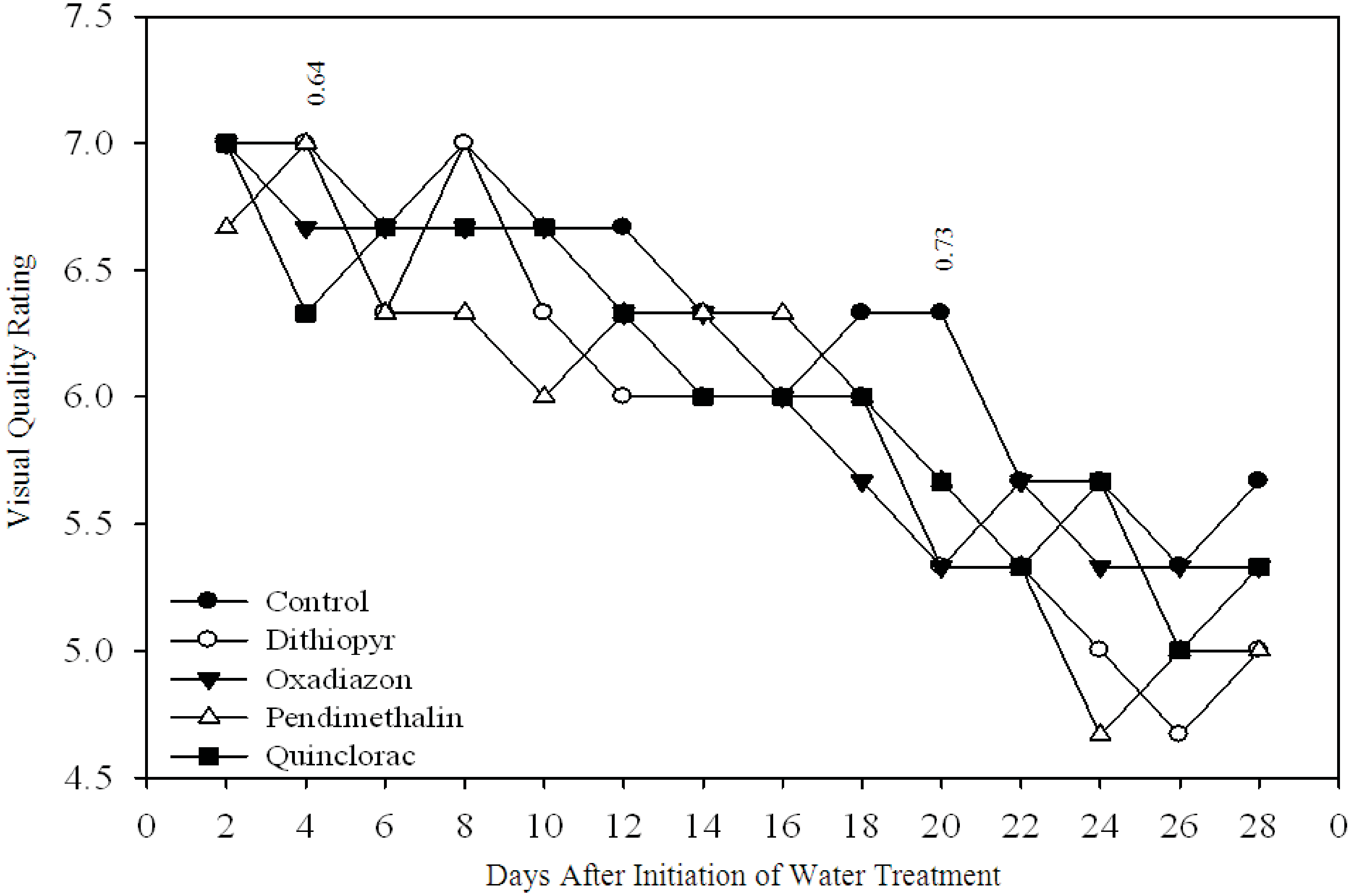

Figure 3.6 Visual quality ratings of the deficit irrigation treatment at 12 weeks after herbicide application at LSU in 2009. Significant differences (p=0.05) are represented by LSD values at the corresponding sampling interval. If no LSD values are present, then no significant differences were observed at the sampling interval.

Plants maintained under the ZI water treatment did not maintain acceptable turf quality at either location for greater than 14d at 12 WAT (Figure 3.7 and Figure 3.8). Plants at the LSU location declined below acceptable turf quality >6d earlier than the plants at the MSU location, likely due to warmer temperatures. Both locations reveal a rapid and severe decline in turf quality over the duration of the 12 WAT observation period. The decline of visual quality ratings at both locations is similar and can be attributed to a healthy root system on plants at both locations and warmer temperatures.

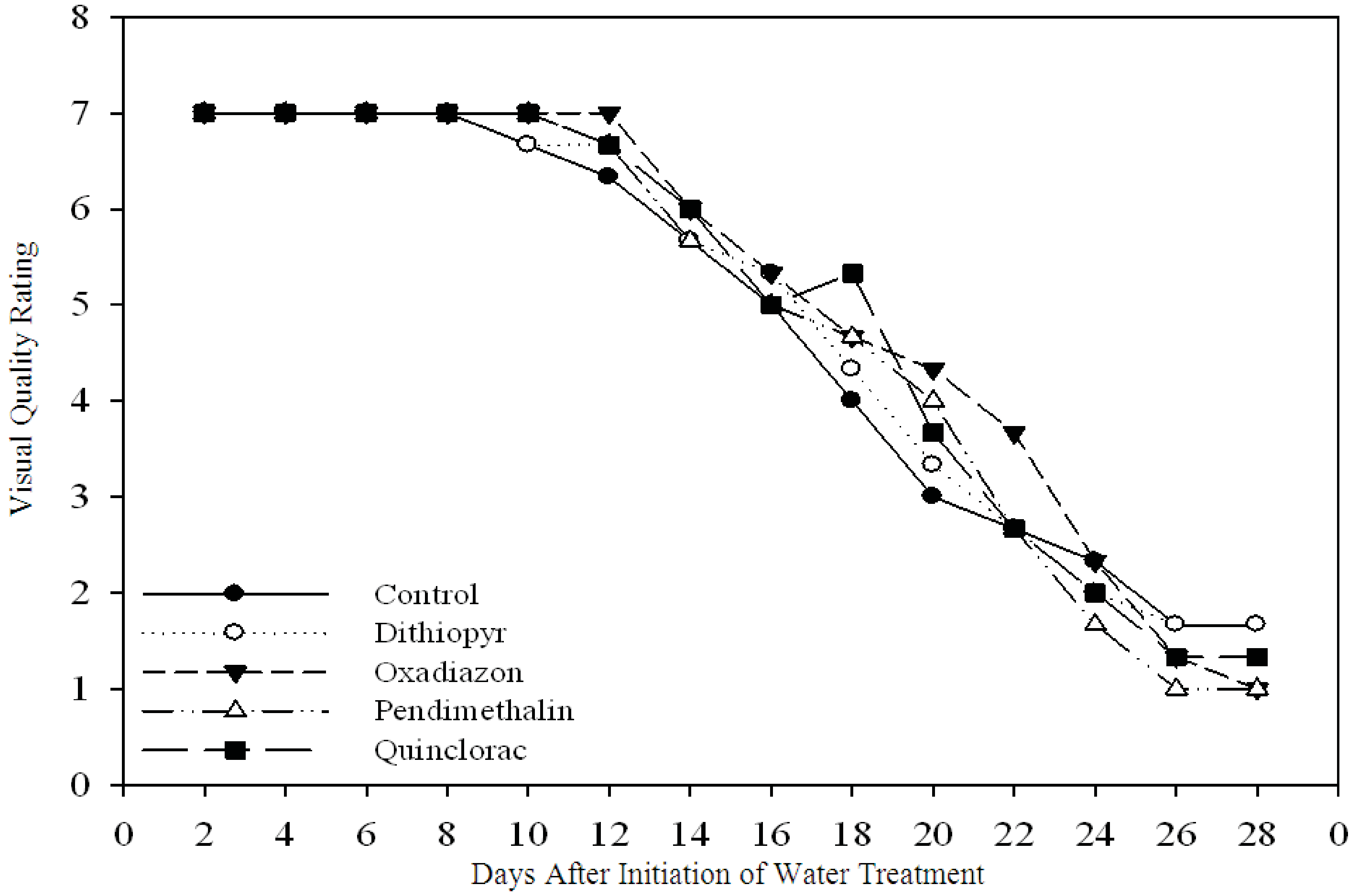

Figure 3.7 Visual quality ratings of the zero irrigation treatment at 12 weeks after herbicide application at MSU in 2009. Significant differences (p=0.05) are represented by LSD values at the corresponding sampling interval. If no LSD values are present, then no significant differences were observed at the sampling interval.

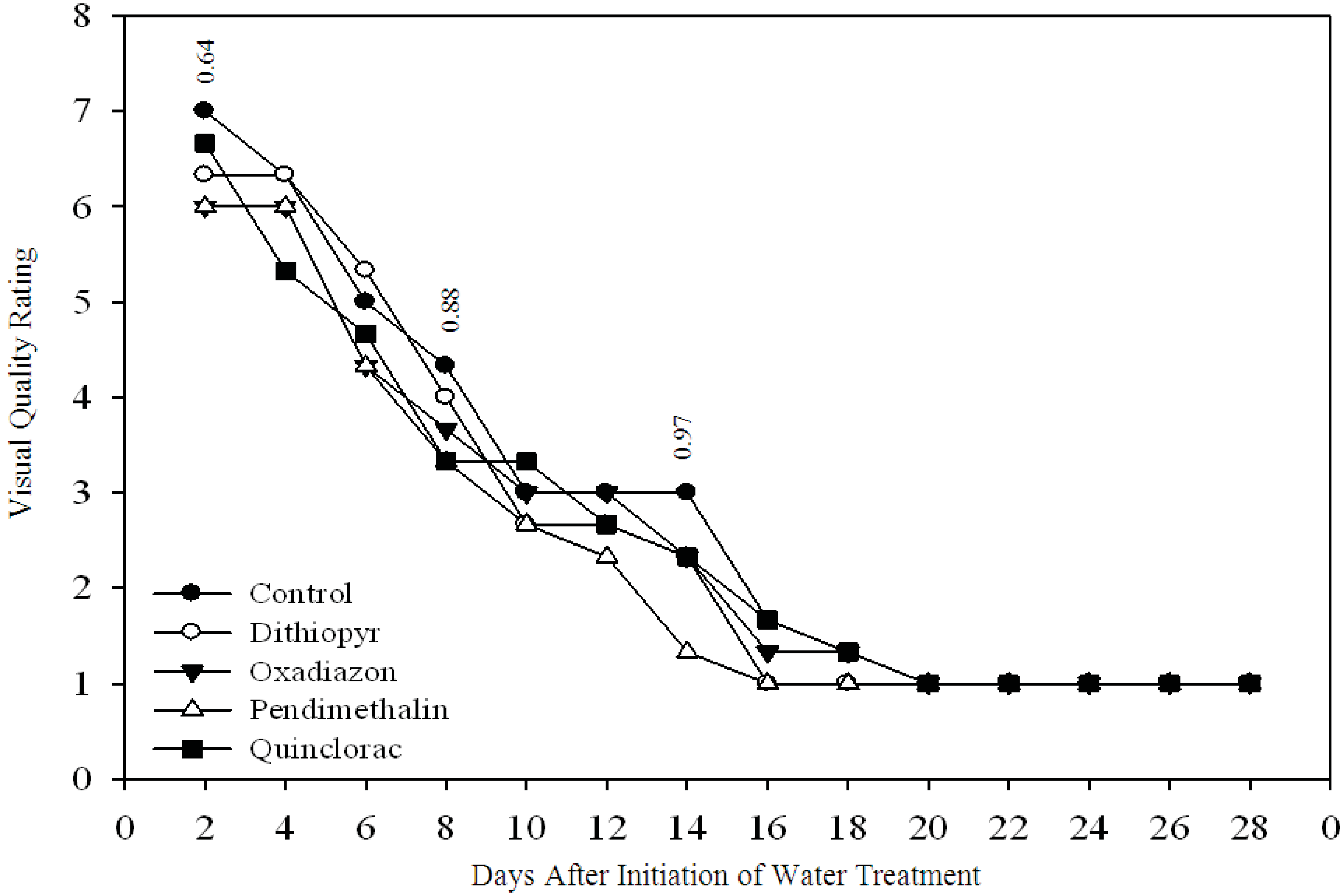

Figure 3.8 Visual quality ratings of the zero irrigation treatment at 12 weeks after herbicide application at LSU in 2009. Significant differences (p=0.05) are represented by LSD values at the corresponding sampling interval. If no LSD values are present, then no significant differences were observed at the sampling interval.

CONCLUSION

The ET water loss from lysimeters treated with dithiopyr and pendimethalin was significantly less than the water loss from the control plants 8 WAT. This suggests that the root system is less robust due to the PRE treatments and not as efficient at removing water as a root system of the untreated control. These findings are in agreement with the previous chapter which states there are differences in the effects of PRE herbicides evaluated on the root architecture of BG. Likewise, there are differences in the total ET water losses at the same observation period (8 WAT). The latter observation period (12 WAT) reveals greater ET water losses for pendimethalin which did not have as great of loss 8 WAT. The change in ET water loss signifies a more healthy and recovered root system on the BG plants evaluated. Changes in ET water on a per-day basis were not as evident and may not be of as much consequence as total ET water loss. Short-term water deficits are not of major concern in turfgrass management, but, long-term deficits may show differences in water loss between PRE herbicides.

The effects of PRE treatment on ET water loss can be visually observed, and plants that were not severely affected by PRE herbicides were possibly able to access and utilize available water held at greater depths within the lysimeters. However, the healthier and unaffected roots, in combination with warmer temperatures, depleted the water reserve more rapidly than plants with negatively affected root systems. The more rapid depletion of available water from the lysimeters led to a drastic decrease in visual plant quality. The rapid decline of visual quality of plants with affected root systems indicate rapid use of water held at shallow depths and limited ability of roots to maintain water uptake as the lysimeters dry from the top. All treatments evaluated yield a decline in visual quality over time, but subtle differences were detected between plants with healthy root systems and plants with root systems negatively affected by dithiopyr and pendimethalin.

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