CHAPTER 4

INFLUENCE OF HUMIC SUBSTANCES ON MOISTURE RETENTION AND PHOSPHORUS UPTAKE IN INTERMOUNTAIN WEST PUTTING GREENS

ABSTRACT

Humic substances are used in turf management by golf course superintendents on putting greens to improve turf health, but their effects on moisture retention in soil have not been studied. Commercial humic substance products applied at recommended rates, and organic acids, including a humic acid without commercial additives, were applied to three golf course putting greens and a research green at Utah State University during the growing season. Humic substances were evaluated for effects on volumetric water content of soil, chlorophyll content and phosphorus uptake of creeping bentgrass under putting green conditions. Three irrigation levels of 80%, 70% and 60% of reference evapotranspiration (ET_o) were also imposed on the turf at the research green. Humic substances did not increase moisture retention in sand-based root zones. Pure humic acid significantly decreased soil volumetric water content compared to the control due to hydrophobic properties of the material. Both humic acid and fulvic acid plots routinely had lower soil moisture content readings than the control during the growing season. There were no differences in chlorophyll content of the turf observed for any humic substance treatment, and uptake of phosphorus by creeping bentgrass was significantly decreased with the application of humic acid. Humic substances may not provide

superintendents with benefits of reducing water or phosphorus fertilizer applications on putting greens.

INTRODUCTION

Creeping bentgrass (*Agrostis palustris* L.) is the predominant cool season grass grown and managed on putting greens in the Intermountain West region of the United States. While adapted to golf course conditions, both the climate and calcareous soil of the Intermountain West can impose difficult growing conditions for this turfgrass species. The transpiration gradient created by climatic factors during the summer can influence the amount of water needed for bentgrass growth. Plus, sand root zones have low water holding capacity that contribute to increased frequency of irrigation needed on putting greens. The calcareous sand commonly used in the Intermountain West can also buffer soil in the alkaline pH range (~ 7.5-8.5), making phosphorus and some micronutrients less available to the turf. Many golf course superintendents are expected to reduce water use, especially during droughts, and minimize fertilizer use while still maintaining extremely high quality turf. Thus, they are always seeking for ways to be more efficient with their management practices while improving turf health. One practice that has gained popularity for its anecdotal ability to reduce irrigation and fertilizer applications is the use of natural organic products, such as those containing humic substances. However, there are still many questions regarding the effectiveness of these products and what exactly these products can do for putting green turf.

Humic substances are popular natural organic products used on golf courses. Humic substances are a component of soil humus, which can be divided into fractions of fulvic acid, humic acid and humin depending on their solubility as a function of pH (Stevenson, 1982). These fractions represent an operationally defined heterogeneous mixture of organic materials (MacCarthy et al., 1990) that are characterized as being yellow or black in color, of high molecular weight, and refractory (Aiken et al., 1985). Humic substances have been studied and used on a variety of agricultural crops for years, but only in the last twenty years have they been studied on turfgrass systems. Of the humic substances that have been studied humic acid is the most common, and results with creeping bentgrass have been highly variable (Cooper et al., 1998).

It has been reported that humic substances have hormone-like effects on plant growth and metabolism (Chen and Aviad, 1990). This includes auxin effects (O'Donnell, 1973) and increased cytokinin levels in creeping bentgrass when treated with humic acid (Zhang and Ervin, 2004). Pertuit et al. (2001) suggested that growth responses resulting from the use of humic substances are due to increased micronutrient availability. Work done by Grossl and Inskeep (1991, 1992) showed humic substances prolonged the bioavailability of phosphorus in solution, and others have reported increased tissue levels of iron (Ayuso et al., 1996; Chen et al., 2004; Mackowiak et al., 2001), zinc (Ayuso et al., 1996; Carey and Gunn, 2000; Chen et al., 2004) and manganese (Ayuso et al., 1996; Liu et al., 1998). However, less mineral effects from humic substances have been reported on creeping bentgrass adequately supplied with nutrients (Cooper et al., 1998; Schmidt et al., 2003).

Humic substances increased plant antioxidant levels in Kentucky bluegrass under moisture stress conditions (Zhang and Schmidt, 1997), and increased photosynthesis in creeping bentgrass (Liu et al., 1998; Zhang et al., 2003, Zhang and Ervin, 2004). Root growth has also been reported on peppers (Arancon et al., 2004) and tomato (Pertuit et al., 2001) treated with humic acid, and root mass (Liu et al., 1998) and length (Cooper et al., 1998) in creeping bentgrass treated with humic acid. However, similar responses have not been observed in the field (Carey and Gunn, 2000; Ervin et al., 2004). One reason for this lack of response is that the effects of humic substances are difficult to isolate due to confounding effects of nutrients and other ingredients often included in humic substance products (Karnok, 2000).

Increasingly, products containing humic substances are appearing in the turf industry market. Claims have been made in advertising and marketing that humic substances increase soil moisture and nutrient availability. While positive growth effects of humic substances on creeping bentgrass have been well documented, the claim of improved moisture retention effects on putting greens has not been studied. This study tested organic acids, including a pure humic acid without nutrient additives, and commercial humic substance products on established putting greens to test the effects humic substances may have on 1) increased water retention in sand putting greens, and 2) improved uptake of phosphorus by creeping bentgrass turf on golf course putting greens.

MATERIALS AND METHODS

Two experiments were conducted. One involved three golf courses in Utah, and the other at a research putting green at Utah State University. Organic acids, including a pure humic acid, and commercial humic substance products were applied to established creeping bentgrass putting greens. Evaluations were done during the summer growing season (June, July, and August) of 2006 and 2007 at the research putting green at Utah State University, and in 2006 at three golf courses in Utah.

The research sites for this experiment were the Utah State University (USU) Greenville Research Farm in North Logan, Utah; Birch Creek Golf Course in Smithfield, Utah; The Country Club in Salt Lake City, Utah; and Talons Cove Golf Course in Saratoga Springs, Utah. At the golf courses, plots were laid out on practice putting greens by the club houses. None of the putting greens were built to USGA specifications (Moore, 2004), with the USU putting green being the closest of all the sites except for a higher percentage of fine (14%) and very fine (9%) sand particles. The Birch Creek and Talons Cove putting greens were built to California style specifications (Davis et al., 1990). The Salt Lake Country Club green was a native soil pushup green with sand top-dressing applied. In all locations, the putting green turf was predominantly creeping bentgrass (*Agrostis palustris* L.) with varying percentages of annual bluegrass (*Poa annua*), and a rootzone consisting of primarily calcareous sands. The depth of each sand rootzone varied with each location from 12cm (4.7 inches) to 18cm (7.1 inches) across each individual putting green. Cultural practices at all of the locations were considered typical for the Intermountain West region of the United States. Details of the management are outlined in (Table C-1). A potentially significant difference between locations was traffic. At the three golf courses, the putting greens were used extensively by golfers, but no traffic was applied on the research putting green at Utah State University in North Logan, UT.

Experimental design

Both experiments were laid out as a split-split-plot design. The experiment with the golf courses used location as the whole plot factor, organic treatment the sub-plot factor, and observation date the sub-sub-plot factor. The organic treatments were randomized in individual treatment plots measuring 1.5 meters by 1.5 meters (5 ft by 5 ft) with three replications. The observation date was the day evaluations were made on the plots. The experiment at the research putting green used irrigation level as the whole plot factor, organic treatment the sub-plot factor, and observation date the sub-sub-plot factor. The organic treatments were randomized in individual treatment plots measuring 1.5 meters by 1.5 meters (5 ft by 5 ft) with three replications. The observation date was the day evaluations were made on the plots. At the research putting green only, each block of organic treatments was centered in a 10.7 meter by 10.7 meter plot (35 ft by 35 ft) irrigation block where different irrigation levels were applied. Irrigation treatments were randomized in a Latin square design consisting of 80%, 70% and 60% of reference evapo-transpiration (ET_o) (Allen et al., 1998). The ET percentages imposed on the turf corresponded to watering approximately every 2-3 days for 80%, every 3-4 days for 70% and every 4-5 days for 60%, based on the climatic conditions at this location. Irrigations to replace 80%, 70% and 60% of ET_o were determined by a Weather Reach controller (Irrisoft Inc., Logan, UT). This controller tracked depletion of water use as estimated by local ET data collected from an ET106 weather station (Campbell Scientific Inc., Logan, UT) and the crop coefficient, or percentage of ET used (Irrisoft Inc., 2004). The irrigation blocks and individual treatment plots were not re-randomized in 2007 at the research putting green, to reduce any confounding factors of possible residual effects from these products occurring in the soil over time. The experimental design, except for irrigation levels was the same at each site. Irrigation treatments were not possible at the golf courses, but irrigation was reduced to stress the turf, at the superintendents' discretion.

Treatments

The plots were treated with granular, reagent grade organic acids, four commercial humic substance products and evaluated against a water only control. These treatments included citric acid, monohydrate (Mallinckrodt Chemicals, Phillipsburg, NJ), gallo-tannic acid (J.T. Baker Chemical Co., Phillipsburg, NJ) and leonardite humic acid (Sigma-Aldrich Inc., St. Louis, MO). The commercial products included a granular humic acid product H-85 (Redox Chemicals Inc., Burley, ID), two liquid humic acid products Focus and Launch (PBI Gordon Corp., Kansas City, MO) and a liquid fulvic acid product (no trade name) (Horizon Ag Products, Modesto, CA). The commercial humic substance products were selected because of humic substance content, particularly humic acid, and availability to turf managers in the Intermountain West. Applications were made at recommended label rates for the commercial products. The rates of application for the organic acid treatments were adjusted from the greenhouse experiment (Chapter 3), to apply the same amount of leonardite humic acid for both the pure humic acid (100% leonardite humic acid) and the H-85 product treatment (50% leonardite humic acid). The citric acid and tannic acid application rates were adjusted to apply the same normalized carbon rate as the pure humic acid treatment. The commercial fulvic acid product did not have a recommended application rate. This treatment was analyzed for total organic carbon, along with the organic acids, using a carbon analyzer that oxidized solution carbon to CO_2, which was subsequently detected by an infrared gas analyzer (Phoenix 8000 Tekmar-Dohrmann, Cincinnati, OH). The fulvic acid treatment was applied at equal carbon rates with the organic acids. The amount of each material applied included 3.7g (0.1 ounces) of citric acid, 2.3g (0.08 ounces) of tannic acid, 2.1g (0.07 ounces) of humic acid, 4.2g (0.14 ounces) of H-85, 5.9ml (0.2 fl. oz) of Focus, 11.02ml (0.4 fl. oz) of Launch and 30ml (1 fl. oz) of fulvic acid. Three separate applications were made at label rates, approximately 30 days apart on 7 June, 5 July and 3 August, 2006 at Birch Creek golf course, and 1 June, 6 July and 2 August, 2006 at the Salt Lake Country Club and Talons Cove golf courses. Applications at the research putting green were made on 5 June, 5 July and 4 August, 2006 and again 1 June, 2 July and 1 August, 2007. All treatments were applied with approximately 532ml (18 fl. oz) of water and made using a CO_2 backpack sprayer at 276 kPa (40 psi).

Evaluation of treatments

Moisture content of the root zones was monitored weekly throughout the summer growing period using a hand-held time-domain reflectometry (TDR) probe. The TDR 100 (Campbell Scientific, Logan, UT) device that was used included a TDR probe that was made by the soil physics lab at Utah State University, connected to a CR10X datalogger (Campbell Scientific, Logan, UT) and a power supply that was assembled to be portable in the field (Figure 4-1). The TDR probe was assembled and calibrated for determining volumetric water content for this application using Win TDR software (Utah State University, 2004), and is considered an accurate tool to measure water content in porous soil (Jones et al., 2005; Robinson et al., 2003). A 15cm (6 inch) probe was used at the research putting green site and Talons Cove golf course, but a 10cm (4 inch) probe was needed at the Birch Creek and Salt Lake Country Club golf courses because of a shallow sand layer. At the research putting green site only, measurements were taken daily for two weeks at the end of July and again in August in both years. This was done to track soil water content more accurately when the different irrigation levels were being applied. Turf color was also measured using a CM1000 chlorophyll meter (Spectrum Technologies, Inc., Plainfield, IL) on the same days soil volumetric water content was measured.

The chlorophyll meter estimated the chlorophyll content in the leaves by measuring reflected wavelengths of light. This reflectance was captured and stored in the meter as a chlorophyll index value of 0 to 999, with higher numbers equaling darker green plots. This index value has been an acceptable quantitative measurement of turf color (Bunderson, 2007; Mangiafico and Guilliard, 2005). The meter was held with an out-stretched hand at approximately 1 meter (3 ft) off the ground with the sun directly behind the user in a direct line with the sample area. Chlorophyll measurements were taken at three random locations within in each plot and averaged to get the plot value. Measurements were taken between 1100am and 1300pm MDT.

To evaluate nutrient uptake effects of the treatments, leaf tissue was collected. This was only possible at the research putting green site due to greater control over the management practices. In order to get enough tissue for a sample the green was not mowed for approximately one week. The golf courses were unable to allow their putting green be un-mowed for that long. Leaf tissue was collected in 2006 and in 2007 with a walking greens mower at the end of the experiment and analyzed in a lab (USU Analytical Laboratories, Logan, UT) for elemental content, most notably for phosphorus. To get a representative sample three random passes were made in each plot. Due to cost constraints tissue from all treatments were not collected. Only tissue from the control and pure humic acid treatments were collected for all factor level combinations to determine differences due to both irrigation levels and treatment effects. The other treatment tissue samples were collected and combined into a single sample within each irrigation level, which served as replication for analysis of treatment effect only. Tissue was not collected for the commercial fulvic acid treatment because additional phosphorus was added to this product by the manufacturer. Tissue was also collected prior to the experiment in each year to provide a baseline of tissue elemental concentrations.

Statistical analysis

The volumetric water content and chlorophyll data were analyzed for differences using the PROC MIXED repeated measures analysis (SAS Institute, 2003). Analysis of the golf course data was done as a split-split-plot design with location as the whole-plot factor, organic treatment the sub-plot factor, and observation date the sub-sub plot factor and repeated on observation date. Replication, or block, and all interactions with replication were considered random. Each year of data at the USU site was analyzed separately as a split-split-plot design with irrigation level as the whole-plot factor, organic treatment as the sub-plot factor, and date as the sub-sub plot factor and repeated on observation date. Replication, or block, and all interactions with replication were considered random.

The phosphorus data was analyzed for differences using the PROC MIXED analysis (SAS Institute, 2003). Each year of data at the USU site comparing the control and humic acid treatments was analyzed separately as a split-plot design with irrigation level as the whole-plot factor, and organic treatment as the sub-plot factor. Replication, or block, and all interactions with replication were considered random.

For the commercial humic substance treatments, each year of data was analyzed separately as a randomized complete block design with organic treatment as a fixed variable and replication, or block, and all interactions with replication were considered random. Residual diagnostics were done to confirm the normal distribution of all data. Random factors and error terms were assumed to be identically distributed with equal variances.

RESULTS AND DISCUSSION

Soil volumetric water content

No differences in soil volumetric water content were observed for any treatment in either experiment. At the golf course sites, volumetric water content was not significantly influenced by the treatments (P=0.47) (Table 4-1; Table D-1). The location × date interaction was a significant effect (P<.0001), and can be explained by the lack of control over irrigation practices at each golf course location. Irrigation at each golf course was done at the superintendents' discretion. The golf course sites had different irrigation practices that ranged from watering every day (Salt Lake Country Club golf course), to watering every 3 to 4 days (Birch Creek golf course) (Table C-1). In the experiment with the golf courses, the distribution of water content means was highest for the Salt Lake Country Club and Birch Creek golf courses compared to the Talons Cove golf course, with a wider distribution occurring early in the experiment, and a narrower distribution later on. Throughout the experiment, the Talons Cove golf course location had lower water content means (Figure 4-2). Also at the golf course sites, location (P=0.0002) and date (P<.0001) were significant effects, and can be attributed to different management practices at each golf course including irrigation timing, watering amounts and syringing practices (Table C-1).

At the research putting green, volumetric water content was not significantly influenced by the treatments in either year, regardless of irrigation level (Table 4-2; Table D-2). The irrigation × date interaction was a significant effect in 2006 (P<.0001) and in 2007 (P<.0001), and like the golf course locations, may be the result of the different number of days at which the measurements were made after irrigation events. In 2006 and 2007, a distribution in water content means for the irrigation levels occurred early in the experiment, and occurred again at the beginning of August, 2006 with the 80% irrigation level having the greatest distribution. The 80% irrigation level often had higher water content means than the other irrigation levels because of more frequent watering, but the distribution was small in 2006 when measurements were taken daily for two weeks in July and August (Figure 4-3). In 2007, the 70% irrigation level had the most distribution between water content means during the July, 2007 two week period of daily measurements, but at the end of August, 2007 the distribution between water content means was not as great for any irrigation level (Figure 4-3). Although the interaction of irrigation on different dates was significant at the research putting green, given the lack of statistical significance between irrigation levels, the differences do not appear to play a biological role.

Even though organic treatment factors did not result in significant differences in soil volumetric water content in the golf course experiment (*P*=0.47), volumetric water content for the control was significantly higher than the humic acid treatment (Table 4-1). Organic treatments did not have a significant influence on soil volumetric water content at the USU site in 2006 (*P*=0.16). However, soil volumetric water content for the Launch product treatment was significantly higher than the humic acid and fulvic acid treatments, and volumetric water content for the control was significantly higher than the fulvic acid treatment (Table 4-2). Frequently throughout the experiment, the control had one of the highest volumetric water content means, while the humic acid and fulvic acid treatments usually had one of the lowest. This was observed at the golf course sites (Figure 4-4), and at the research putting green for the 60% ET_o (Figure 4-5), 70% ET_o (Figure 4-6) and 80% ET_o irrigation levels (Figure 4-7), respectively.

The humic substances used in these experiments did not increase water holding capacity in sand putting greens. In fact, the humic substances contributed to lower moisture retention than the control, and decreased the amount of water in the soil. This was likely due to hydrophobic properties of these materials (Karnok and Tucker, 2001), and the resulting decrease in the amount of water available to the roots. Throughout this study, volumetric water content for humic acid was approximately 1% lower than the control, and the reduction in soil moisture caused by humic acid may reduce turf quality and increase the irrigation frequency of putting green turf. In a greenhouse study, irrigating simulated putting greens with humic acid also demonstrated hydrophobic properties, and resulted in drying down of the root zone two days sooner, leading to more frequent irrigations (Chapter 3).

Prolonged use of humic substances on putting greens may contribute to greater soil hydrophobicity (Murphy et al., 1990) and increase localized dry spots (Karnok and Tucker, 1999; Miller and Wilkinson, 1979) requiring the use of wetting agents as a potential way to deal with this problem (Karnok and Tucker, 2001; Mueller and Kussow, 2005). High pH treatments have also been an effective tool to reduce soil hydrophobicity of putting greens, but creeping bentgrass had varying degrees of phytotoxicity associated with the treatments (Karnok et al., 1993).

Chlorophyll meter

No differences in the color index of the turf as measured by the chlorophyll meter were observed for any treatment in either experiment. At the golf course sites, chlorophyll content was not significantly influenced by the treatments (P=0.23) (Table 4-1; Table D-1). The location × date interaction was significant (P<.0001), and may be explained by the lack of control over irrigation practices at each golf course. Distribution in the chlorophyll means was observed between golf course locations early in the experiment, but was much closer later on with the Birch Creek location routinely having higher chlorophyll means throughout the experiment (Figure 4-2). As expected, location (P=0.009) and date (P<.0001) were significant effects, and may be attributed to different management practices at each golf course, including fertilization, irrigation timing, watering amounts, and syringing practices (Table C-1).

At the research putting green, chlorophyll content was not significantly influenced by the treatments in either year, regardless of irrigation level (Table 4-2; Table D-3). The irrigation × date interaction was significant at the research putting green site in 2006 (*P*=0.003) and in 2007 (*P*<.0001), and like the golf course locations, many of the chlorophyll content readings were taken after a different number of days after a fertilization or irrigation event. In 2006 and 2007, distribution in the chlorophyll means was observed between irrigation levels early on in the experiment. The 60% irrigation level distribution was somewhat lower in 2006 compared to the other irrigation levels, and the 70% irrigation level distribution was somewhat lower in 2007. However, in both years all irrigation levels had much closer distribution between chlorophyll means later on (Figure 4-8). Although the interaction of irrigation on different dates was significant at the research putting green, given the lack of statistical significance between irrigation levels, differences do not appear to play a biological role.

Even though organic treatment factors did not result in significant differences in chlorophyll content in the golf course experiment (*P*=0.23), chlorophyll meter readings for the citric acid and humic acid treatments were significantly higher than the Launch product treatment (Table 4-1). Organic treatments did not have a significant influence on chlorophyll content at the research putting green in 2006 (*P*=0.37), but chlorophyll meter readings for the control and tannic acid treatments were significantly higher than the H-85 product treatment (Table 4-2).

No formal visual quality ratings of the turf were taken, but a lack of chlorophyll meter reading differences were observed for the humic substances at the golf courses, and the research putting green in both years. Visual turf quality ratings increased on fairway creeping bentgrass with humic acid application (Zhang et al., 2003), but a lack of differences have also been reported (Carey and Gunn, 2000) including one study on shaded putting green turf (Ervin et al., 2004). Lack of chlorophyll meter reading differences in this study suggest turf color, and possibly turf quality, is not improved with humic substance application on creeping bentgrass managed under putting green conditions.

Phosphorus uptake

Phosphorus uptake as measured by tissue concentration was significantly influenced by the treatments in 2006 (P=0.04), but not in 2007 (P=0.09) (Table 4-3; Table D-4). In 2006, tissue levels of phosphorus were significantly higher for the control (0.43%), compared to the humic acid treatment (0.41%) on average (Table 4-3). In 2007, although no significant difference was found, the control had a higher tissue concentration of phosphorus than the humic acid treatment. Additionally, the tissue concentration of phosphorus was not improved on simulated putting greens in a greenhouse experiment irrigated with humic acid (Chapter 3).

Variable results of improved turfgrass phosphorus uptake with the application of humic acid have been reported in other studies with creeping bentgrass. There was no increase in tissue concentration reported in creeping bentgrass grown in sand (Liu et al., 1998) or solution (Cooper et al., 1998) when humic acid was foliar applied, but tissue levels were increased when humic acid was incorporated into sand (Cooper et al., 1998). No tissue phosphorus increases were found on rough fescue (Dormaar, 1975) or perennial ryegrass (Guar, 1964). The humic substance products used in this study may not improve the uptake of phosphorus by turfgrass. Turfgrass plants are efficient at the uptake of phosphorus (Christians, 2004), including creeping bentgrass capable of obtaining adequate amounts of phosphorous even at low levels (Johnson et al., 2003). The differences in uptake may have been influenced by the distribution of roots in the soil. Based on results from a greenhouse experiment (Chapter 3), the hydrophobic nature of the humic substances present near the soil surface may have facilitated the movement of water into the subsurface, and consequently root growth followed water distribution. Fewer roots in the upper rootzone would not have accessed available phosphorus when fertilizers were surface applied.

Although not an original objective, other nutrient levels in plant tissue were affected by the application of humic substances in this study including sulfur (S), which was significantly lower for the humic acid treatment in 2006 (P=0.002) (Table 4-3; Table D-4). In 2007, tissue concentrations of S were similar to 2006 levels for both treatments, but the differences were not statistically different (P=0.19). Although other nutrients concentrations were not significantly influenced by the treatments, all mean nutrient concentrations for the humic acid treatment were lower than the control in both years with the exception of magnesium (Mg) in 2006 (Table 4-3). In a greenhouse study, high tissue concentrations of sodium (Na) were found with the application of the pure humic acid product (Chapter 3). This was most likely due to high Na levels still present from the sodium hydroxide extraction process. High Na may not be present in all humic substances applied to turf, but Rossi (2004) found increased levels in some commercial products. Excess Na may contribute to soil structure and poor water infiltration, but may not be a concern on sand. However, other problems such as inhibition of other cations being absorbed by the plant may be a problem (Carrow and Duncan, 1998).

Although not an original objective, one significant finding of this study was the potential to irrigate creeping bentgrass at 60% ET_o during the summer months (June through August) in the Intermountain West with no reduction in turf quality. Due to the lack of irrigation level differences for chlorophyll meter readings in 2006 (P=0.83) and 2007 (P=0.99), it appears that irrigating approximately every 4 to 5 days may be a way to conserve water without sacrificing turf quality. However, this result was obtained on a research putting green that did not receive the level of traffic that would be experienced at a typical golf course.

Superintendents looking to conserve water and reduce phosphorus fertilization may not be best served by using humic substance products. These products may offer other benefits to turf, but their use may require more frequent applications of water to putting greens and additional wetting agent applications to reduce localized dry spots because of the hydrophobic tendencies of these materials.

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Table 4-1. Effect of organic acid and humic substance product application† on volumetric water content (VWC) of soil and chlorophyll content (color) of creeping bentgrass at three golf courses†† in 2006.

Treatment			Volumetric water content§	Chlorophyll content¶
			%	color
Control			0.176 a‡	226 ab
Citric acid			0.174 ab	230 a
H-85			0.171 ab	226 ab
Focus			0.170 ab	226 ab
Fulvic acid			0.169 ab	226 ab
Tannic acid			0.168 ab	227 ab
Launch			0.168 ab	223 b
Humic acid			0.160 b	228 a
ANOVA				
Effect	**df VWC**	**df color**		
Location	2	2	***	**
Treatment	7	7	ns	ns
Location × Treatment	14	14	ns	ns
Date	9	8	***	***
Location × Date	18	16	***	***
Treatment × Date	63	56	ns	ns
Location × Treatment × Date	126	112	ns	ns

*, **, ***, ns, significant at $P \leq 0.05$, 0.01, 0.001, or not significant respectively.
†Treatments were foliar applied according to the label in June, July and August.
‡Means within same column with same letter are not different significantly $P = 0.05$.
§Volumetric water content was measured with a time-domain reflectometry probe.
¶Chlorophyll was measured with a CM-1000 chlorophyll meter.
††Locations included Birch Creek (Smithfield, UT), Talons Cove (Saratoga Springs, UT) and Salt Lake Country Club (Salt Lake City, UT) golf courses.

Table 4-2. Effect of organic acid and humic substance product application† on volumetric water content (VWC) of soil and chlorophyll content (color) of creeping bentgrass at the research putting green†† in 2006 and 2007.

Treatment	Volumetric water content§		Chlorophyll content¶	
	2006	2007	2006	2007
	%		color	
Launch	0.122a‡	0.118a	173ab	179a
Control	0.121ab	0.118a	177a	178a
Citric acid	0.119abc	0.116a	174ab	175a
H-85	0.119abc	0.114a	172b	177a
Focus	0.119abc	0.115a	176ab	178a
Tannic acid	0.118abc	0.115a	172b	177a
Humic acid	0.117bc	0.112a	174ab	178a
Fulvic acid	0.116c	0.112a	173ab	177a

ANOVA

Effect	**df VWC**		**df color**					
	2006	2007	2006	2007				
Irrigation	2	2	2	2	ns	ns	ns	ns
Treatment	7	7	7	7	ns	ns	ns	ns
Irrigation × Treatment	14	14	14	14	ns	ns	ns	ns
Date	44	48	41	38	***	***	***	***
Irrigation × Date	88	96	82	76	***	***	**	***
Treatment × Date	308	297	287	266	ns	ns	ns	ns
Irrigation × Treatment × Date	616	673	574	532	ns	ns	ns	ns

*, **, ***, ns, significant at $P \leq 0.05$, 0.01, 0.001, or not significant respectively.
†Treatments were foliar applied according to the label in June, July and August.
‡Means within same column with same letter are not different significantly P=0.05.
§Volumetric water content was measured with a time-domain reflectometry probe.
¶Chlorophyll was measured with a CM-1000 chlorophyll meter.
††Located at the Utah State University, Greenville Research Farm, North Logan, UT.

Table 4-3. Effect of humic acid application[†] on nutrient concentration of creeping bentgrass at the research putting green[§] in 2006 and 2007.

Treatment		P		K		Ca		Mg		S		Fe		Cu	Zn	Mn	Na
		2006	2007	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007	2007			
		(%)										(mg/kg)					
Control		0.43a[‡]	0.43a	1.4a	1.2a	0.74a	0.75a	0.26a	0.29a	0.32a	0.31a	234a	523a	9.6a	30a	31a	55a
Humic acid		0.41b	0.42a	1.5a	1.1a	0.69a	0.68a	0.26a	0.28a	0.29b	0.29a	214a	421a	9.5a	27a	27a	51a
ANOVA																	
Effect	**df**																
Irrigation	2	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Treatment	1	*	ns	ns	ns	ns	ns	ns	ns	**	ns	ns	ns	ns	ns	ns	ns
Irrigation × Treatment	2	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

*, **, ***, ns, significant at $P \leq 0.05$, 0.01, 0.001, or not significant respectively.
[†]Humic acid was foliar applied at 9 kg ha^{-1} in June, July and August thirty days apart.
[‡]Means within same column with same letter are not different significantly P=0.05.
[§]Located at the Utah State University, Greenville Research Farm, North Logan, UT.

Figure 4-1. Time-domain reflectometry (TDR) probe and datalogger used to measure and store soil volumetric water content in the field experiments.

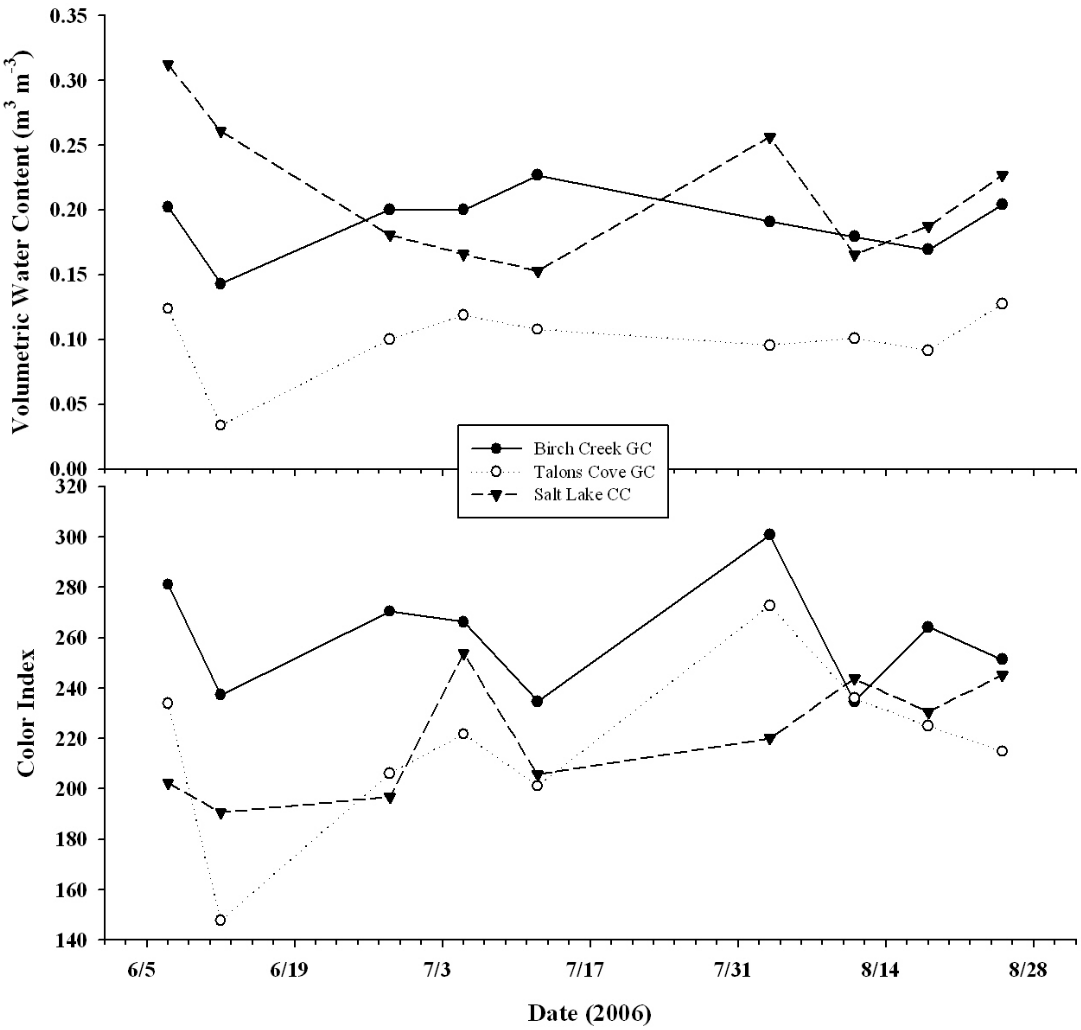

Figure 4-2. Location × date interaction at the golf course sites for soil volumetric water content and chlorophyll (color index) means in 2006.

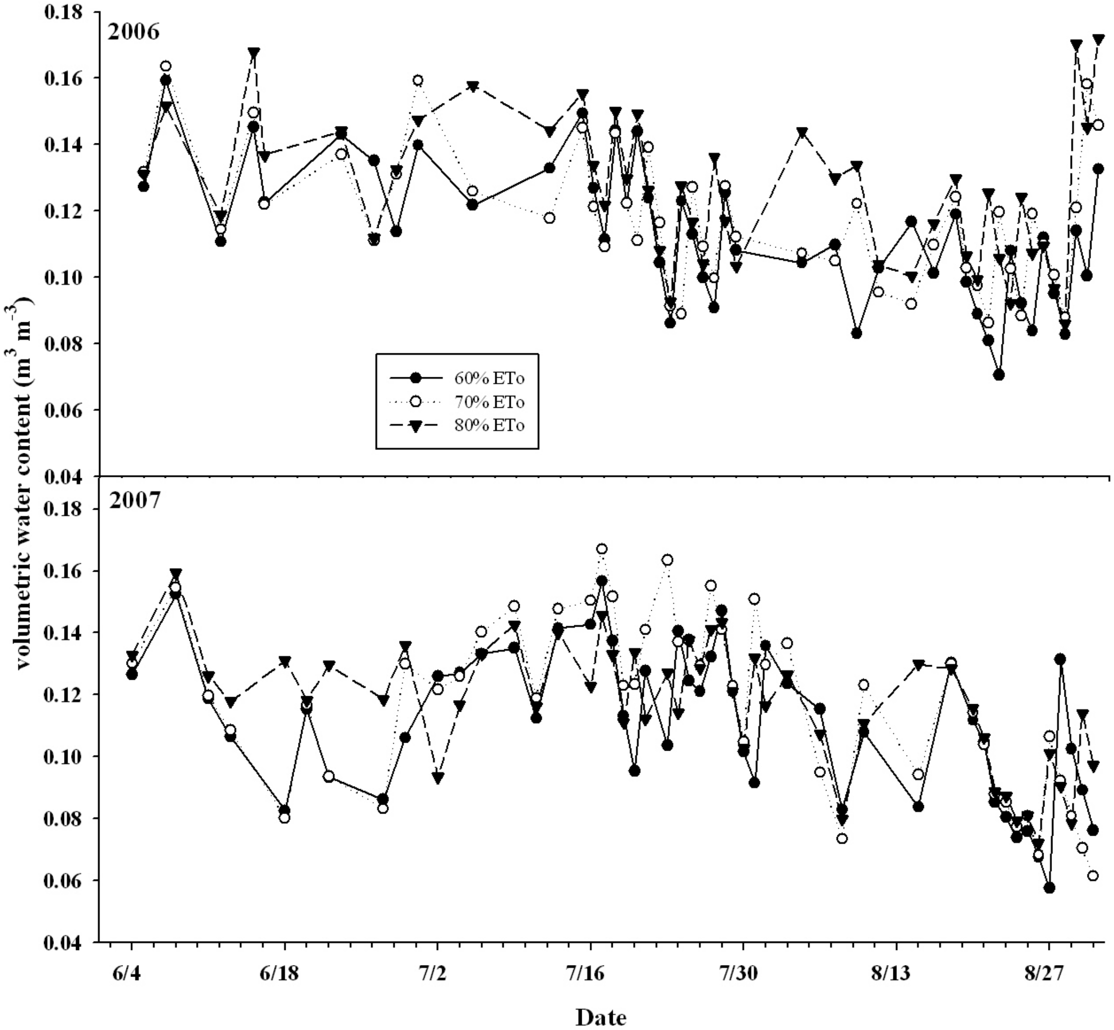

Figure 4-3. Irrigation × date interaction at the research putting green for soil volumetric water content means in 2006 and 2007.

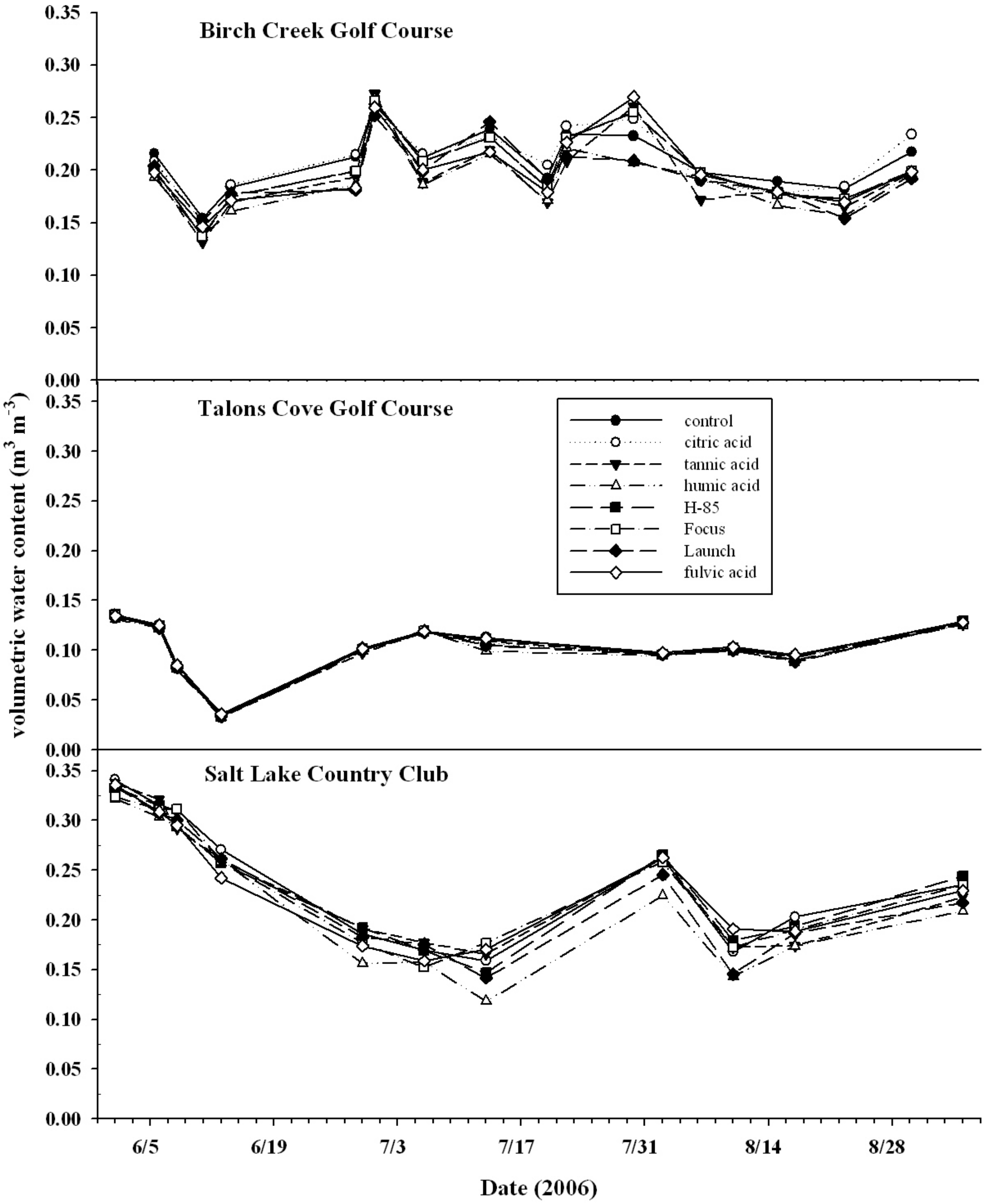

Figure 4-4. Soil volumetric water content means for organic acids and humic substance products at golf course locations in 2006.

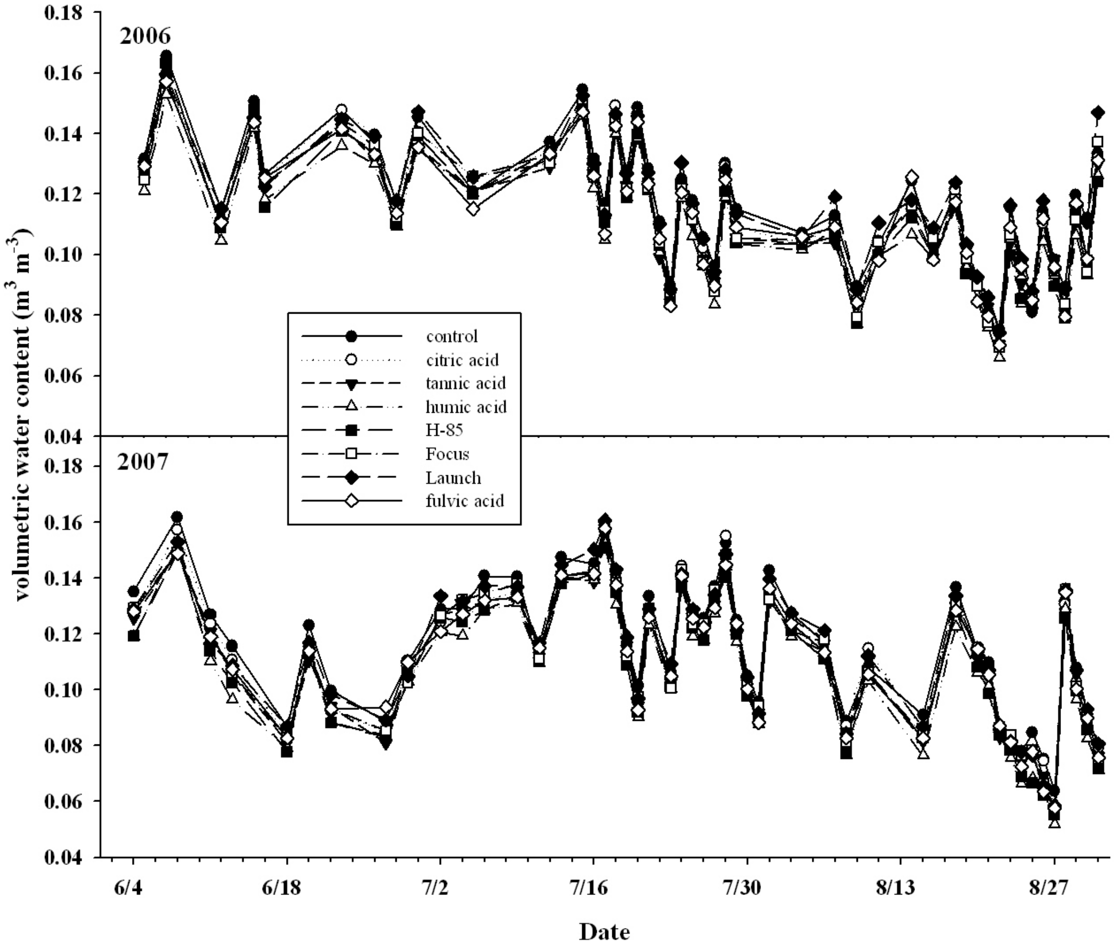

Figure 4-5. Soil volumetric water content means for organic acids and humic substance products for the 60% ET_o irrigation level at the research putting green in 2006 and 2007.

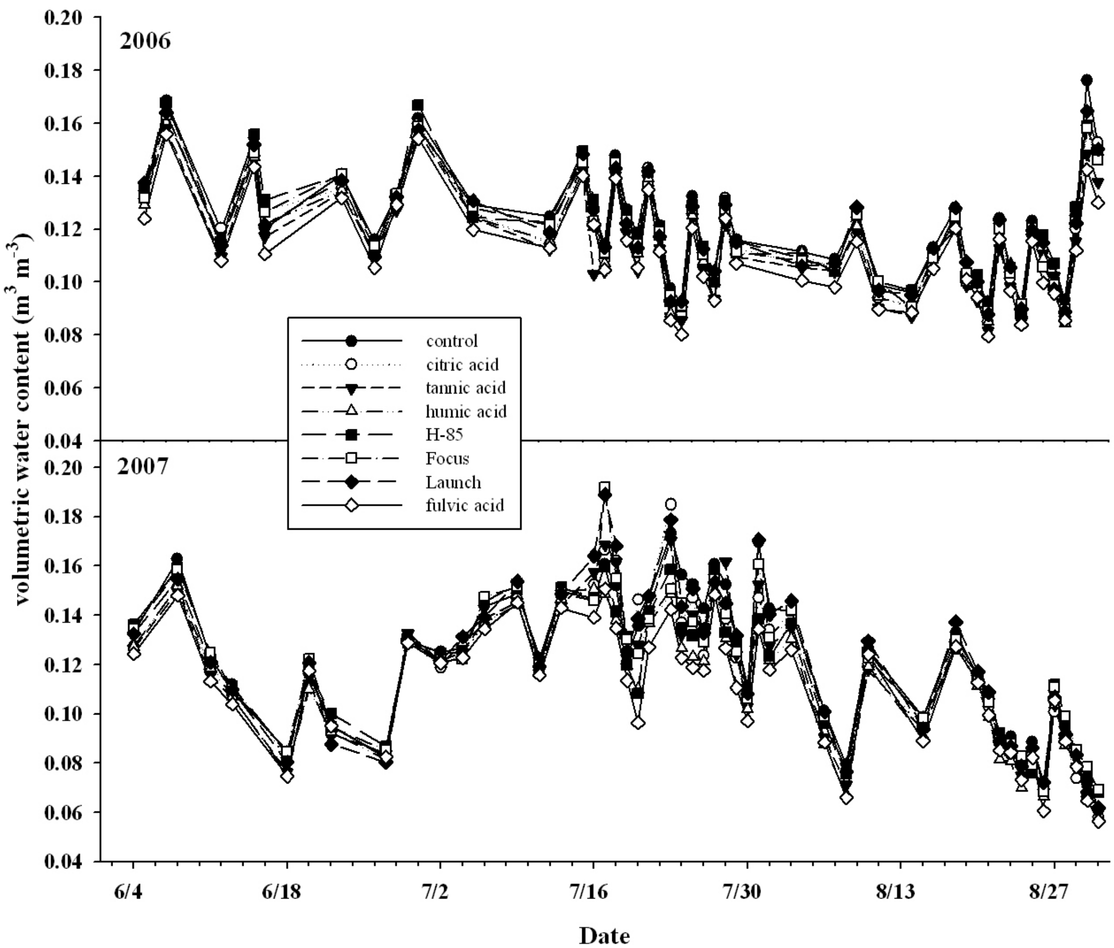

Figure 4-6. Soil volumetric water content means for organic acids and humic substance products for the 70% ET_o irrigation level at the research putting green in 2006 and 2007.

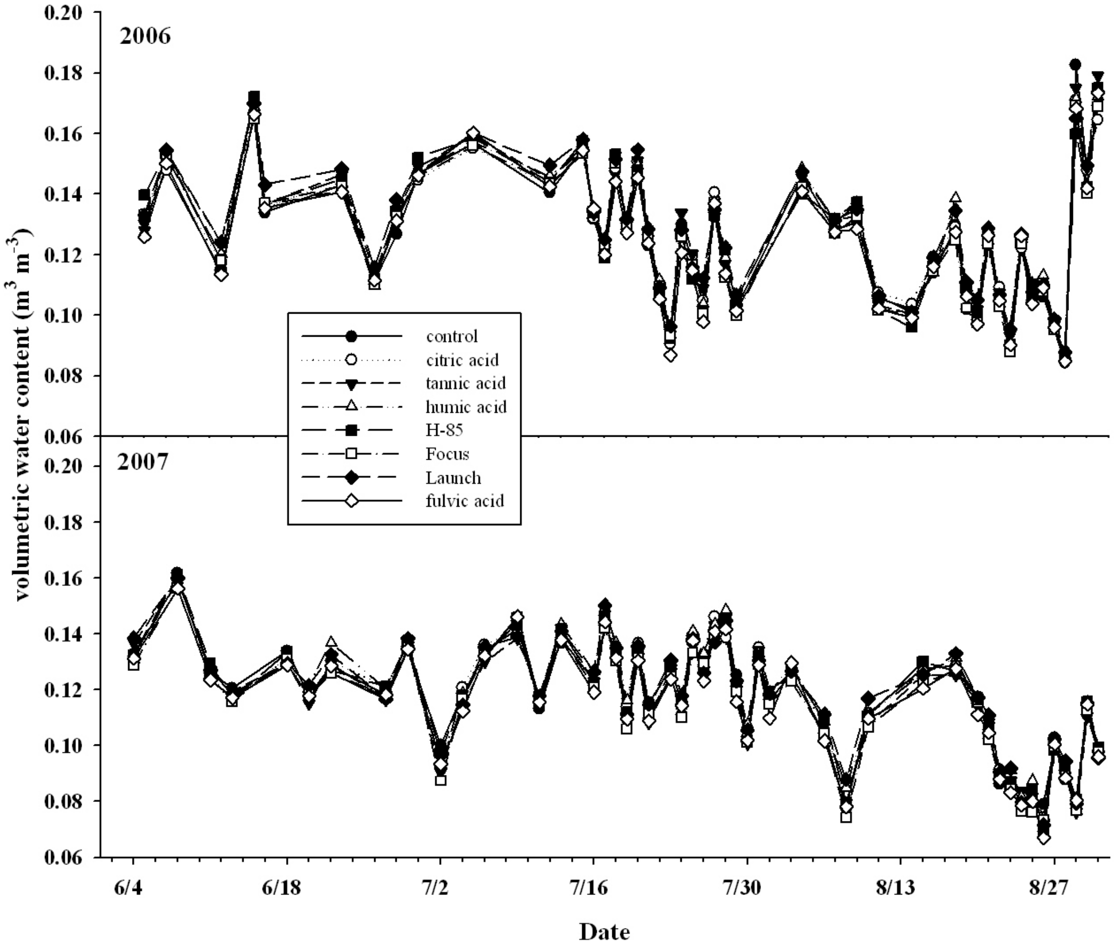

Figure 4-7. Soil volumetric water content means for organic acids and humic substance products for the 80% ET_o irrigation level at the research putting green in 2006 and 2007.

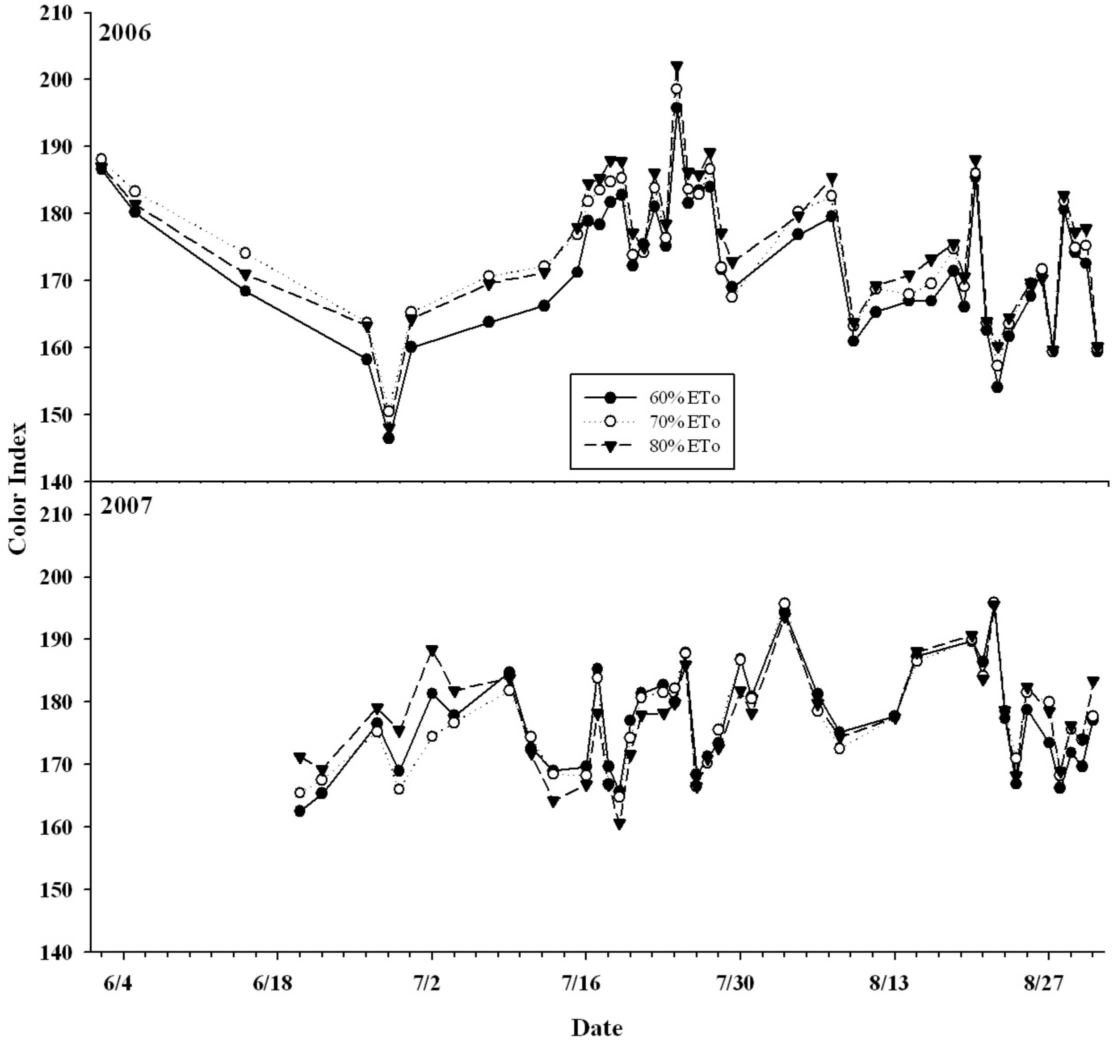

Figure 4-8. Irrigation × date interaction at the research putting green for chlorophyll (color index) means in 2006 and 2007.