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Experiments were conducted at Utah State University to to evaluate the effects of natural organic acids, including a pure humic acid, on water retention in simulated calcareous sand-based putting greens, and nutrient availability, particularly P, to creeping bentgrass growing on the simulated greens. None of the organic acid treatments improved water retention in the simulated greens and humic acid-treated greens required more frequent irrigation than the untreated greens indicating that they were drying out more quickly. The addition of humic acid did not result in higher tissue concentrations of nutrients nor increases in top-growth, dry root mass, or root:shoot ratios compared to the other treatments.

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PURPOSE

The purpose of *USGA Turfgrass and Environmental Research Online* is to effectively communicate the results of research projects funded under USGA's Turfgrass and Environmental Research Program to all who can benefit from such knowledge. Since 1983, the USGA has funded more than 350 projects at a cost of $29 million. The private, non-profit research program provides funding opportunities to university faculty interested in working on environmental and turf management problems affecting golf courses. The outstanding playing conditions of today's golf courses are a direct result of ***using science to benefit golf***.

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Influence of Humic Acid on Water Retention and Nutrient Uptake in Simulated Putting Greens

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SUMMARY

Products that contain humic acid are frequently applied to creeping bentgrass (*Agrostis stolonifera)* on putting greens to improve turf health and are marketed to enhance nutrient uptake and possibly aid in retaining water in drought-prone environments. However, information on the role of humic acid in increasing soil water retention is limited. Pure organic acids - humic acid, tannic acid, and citric acid - were added to simulated creeping bentgrass putting greens at normalized carbon rates (250 mg C L^{-1}) as solutions through an automated irrigation system. Volumetric water content, irrigation frequency, shoot and root growth, and tissue nutrient concentration of the turf were measured.

- None of the organic acid treatments improved water retention in the simulated greens. The humic acid treated greens required more frequent irrigation than the untreated greens indicating that they were drying out more quickly.
- Addition of humic acid did not result in higher tissue concentrations of nutrients nor increases in top-growth, dry root mass or the root:shoot ratio compared to the other treatments.
- Creeping bentgrass root length was greater in the greens treated with humic acid compared to the untreated control, but may be related to the lower soil water content.

Creeping bentgrass is the predominant cool-season species grown on golf putting greens in North America. The semi-arid climate and calcareous sands often used in the Intermountain West region can stress this species and create a need for frequent irrigation. Calcareous sand may also buffer soil pH in the alkaline pH range (~ 7.5-8.5) rendering phosphorus (P) and micronutrients less available. Adding naturally derived organic products to putting greens, including humic substances, is a management practice gaining popularity for its potential to reduce irrigation and fertilizer applications. Humic substances are components of soil humus, and consist of fulvic acid, humic acid, and humin fractions. These materials are involved in mineral weathering, mobilization and transport of metal ions, sorption of pesticides, formation of soil aggregates, and cation exchange capacity of soils (30). Humic substances - humic acid most commonly - have been studied and used for years as an amendment in agricultural cropping systems but only recently studied in turfgrass systems.

Humic substances have hormone-like effects on plant growth and metabolism (5) including auxin-like responses (26) and increased cytokinin levels (37). However, results have been variable. With creeping bentgrass, photosynthesis increased (21, 37, 39), as well as root mass (21) and root length (9) when treated with humic acid. However, responses of greater chlorophyll content have not been observed under field conditions (34). One possible reason for this lack of response is that nutrients and other ingredients added to commercial products confound observed growth responses (17). Coal-derived humic substances have increased water retention and water holding capacity of soils with low water holding capacities

Creeping bentgrass sod was cut from a research green and grown in tubs in a greenhouse to simulate golf course putting greens.

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(28), but, in general, studies reporting enhanced soil water retention from humic substances are limited.

A more common and widely cited phenomenon related to water retention in sand-based turf systems is "localized dry spot" (LDS) caused by the formation of water repellent soils (8, 10). Hallett (14) defines soil water repellency as a reduction in water retention and the rate of wetting in soil due to hydrophobic coatings on soil particles. There are a number of factors that can contribute to the formation of LDS in golf greens (18), including humic and fulvic acids being known to form organic coatings on soil particles causing soil hydrophobicity (23, 31), that can contribute to greater incidences of water repellent soil on putting greens (32).

Additionally, organic acids, including humic acid, can inhibit the precipitation of calcium phosphate minerals keeping P in solution longer (12, 13). In addition to enhancing P bioavailability, humic acids have also increased the availability of micronutrients (2, 6, 21, 22, 27). The objectives of this study were to evaluate the effects of natural organic acids, including a pure humic acid, on 1) water retention in simulated calcareous sand-based putting greens, and 2) nutrient availability, particularly P, to creeping bentgrass growing on the simulated greens.

MATERIALS AND METHODS

Applying Humic Acid to Simulated Greens

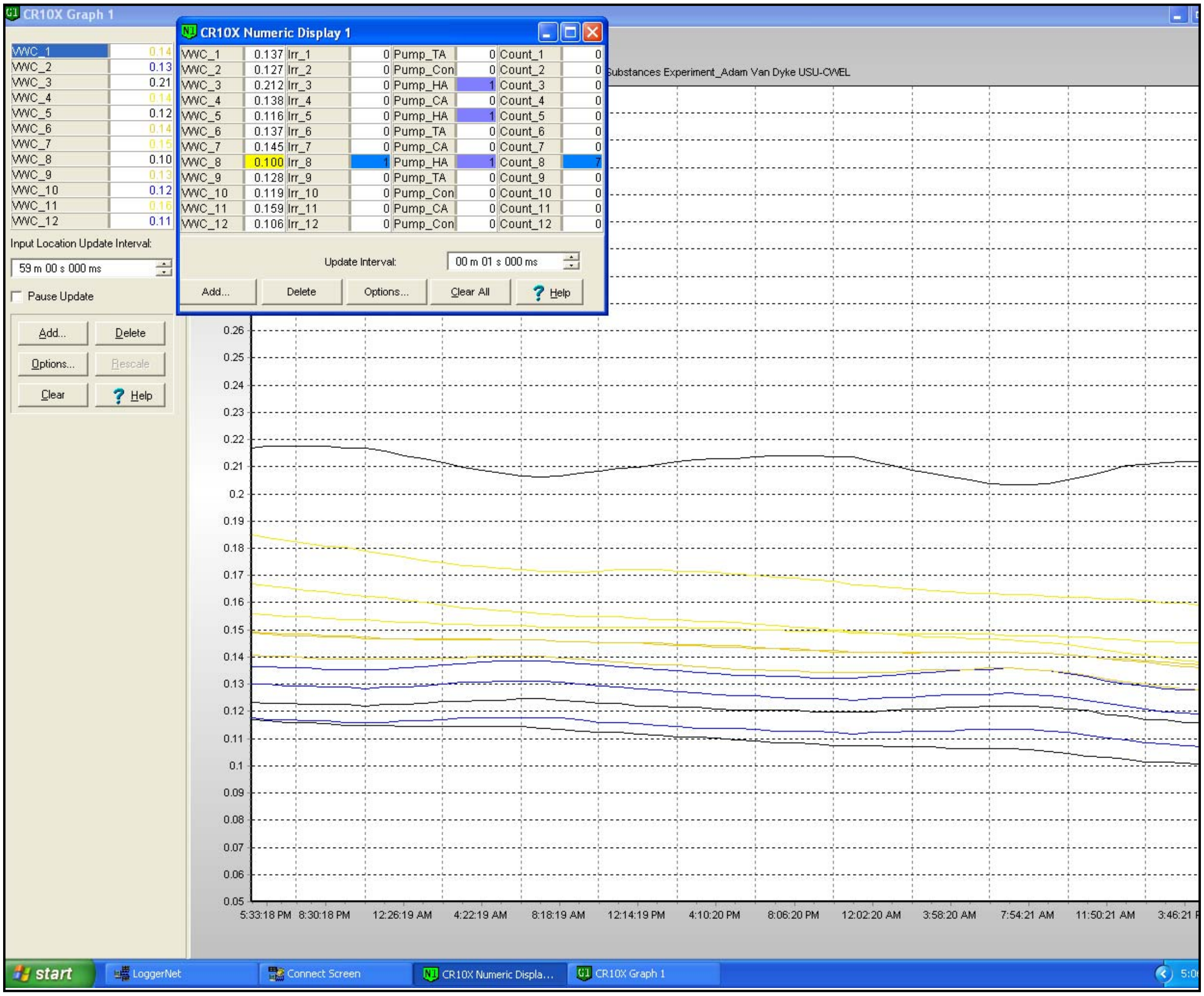
'Dominant' creeping bentgrass sod was cut from a research putting green in North Logan, Utah and grown in 9.5 in. x 14 in. x 12 in. deep plastic tubs filled with calcareous sand having a 3.2% $CaCO_3$ equivalent (Staker-Parson Companies, Brigham City, UT) in a greenhouse. The calcareous sand was mixed with finely-ground sphagnum peat moss at 90% sand and 10% peat (on a volume basis) to match the soil of the sod. This combined medium contained 96% sand, 2% silt, and 2% clay, with a pH of 7.8, EC of 0.25 dS m^{-1}, 0.4 % organic matter, and 2.4 mg kg^{-1} of P. The sod roots were trimmed to 5 inches before planting.

The tubs were placed in pairs into larger plastic tubs (19 in. x 23 in. x 9.5 in. deep) on top of 1.5 inches of gravel with holes drilled in both tubs for drainage. This simulated a USGA putting green profile (24) and was a modification of methods described by Slavens (29). Aluminum foil was wrapped around the tubs to reflect solar radiation and prevent rootzone heating. The experiment was repeated three times with each run lasting three months after an establishment period of about three months. The first run began June 21, 2006 and ended August 25, 2006. The second run began January 16, 2007 and ended April 4, 2007. The third run began July 30, 2007 and ended October 30, 2007.

Three organic acids were applied to the turf in solution during irrigation at normalized carbon rates of 250 mg C L^{-1} and evaluated against a control treatment of de-ionized water. The organic acids used were leonardite humic acid (Sigma-Aldrich Inc., St. Louis, MO), gallo-tannic acid (J.T. Baker Chemical Co., Phillipsburg, NJ), and citric acid monohydrate (Mallinckrodt Chemicals, Phillipsburg, NJ). Application rate of the treatments was determined in a pilot study (33) and from other greenhouse studies where humic acid was applied to creeping bentgrass (9, 21).

Although humic acids derived from different sources (i.e., water, soil, peat, coal, etc.) will vary in chemical composition, the humic acids

Soil moisture probes buried in each tub were used to continuously measure moisture content of the rootzone and control the irrigation system that delivered the treatments to the turf.



Data from the soil moisture probes was displayed on a computer screen to monitor the water content in each tub including when a tub reached the 10 % water content threshold (highlighted yellow) and began irrigating (highlighted blue).

most frequently used in commercial turf products are extracted from "brown coal"sources, often referred to leonardite. Our "pure" humic acid was also from a brown coal source, yet it was pure in that it was the original extracted material without additives (essential plant nutrients) which are often added to commercial products.

Although humic acid is a common ingredient in turf management products, tannic and citric acids are not. These acids were included to represent a range of oxygen functional groups, and selected based upon their size, carboxylic acid functional group content (-COOH), availability, and relative costs. The ability of organic acids to inhibit phosphorus retention processes in soils is related to their COOH content and size (12). We wanted to include fulvic acid, but unfortunately its use was cost prohibitive, and it is not readily available. Tannic acid has a similar COOH content to fulvic acid (12) and should be an appropriate substitute for fulvic acid.

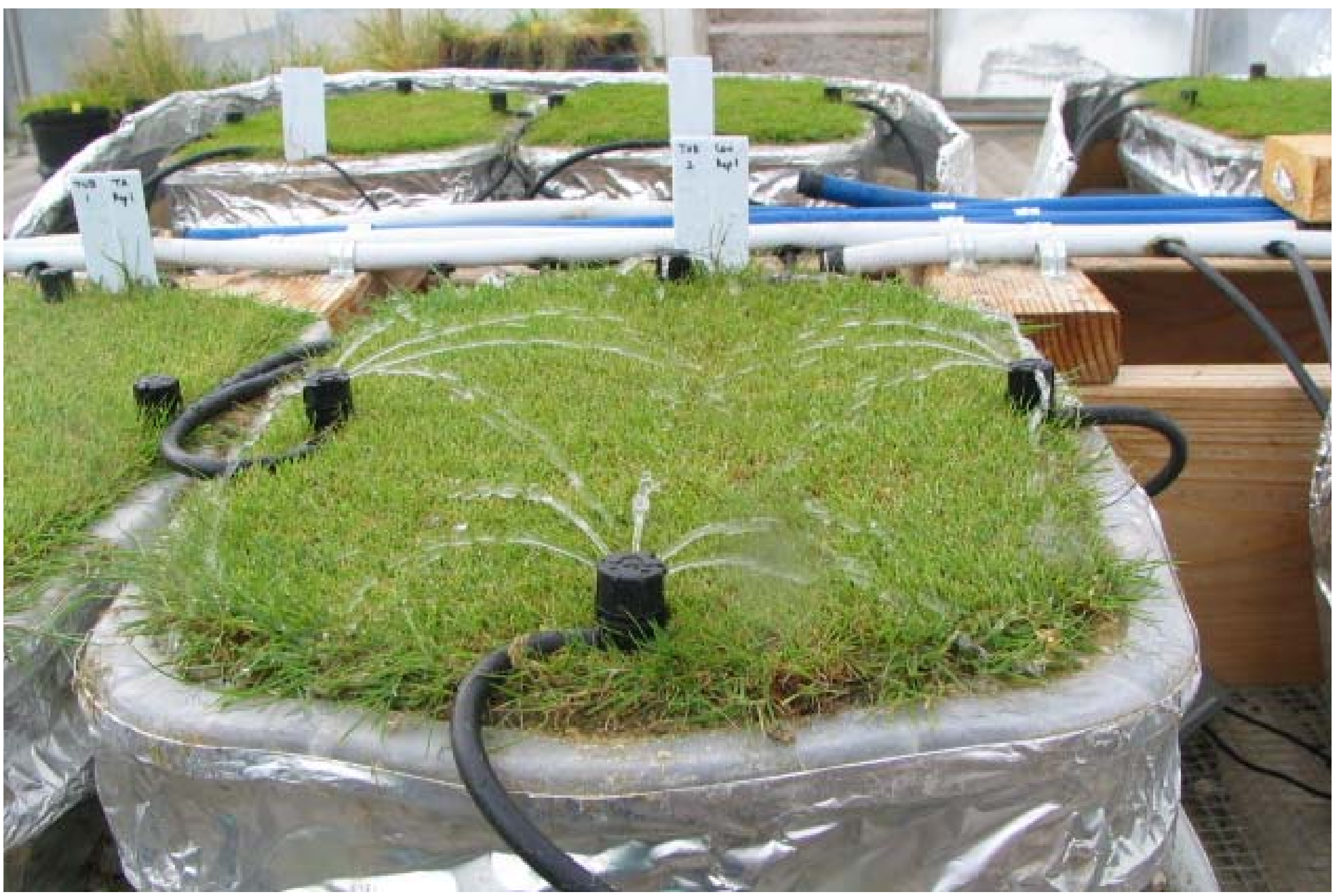
Irrigation System

The treatments were applied to the turf through an automated irrigation system triggered by the volumetric water content (VWC) of the soil as measured by a soil moisture probe. A capacitance soil moisture probe (EC-20, Decagon Devices Inc., Pullman, WA) was calibrated and buried 5 inches deep in the profile of each tub and connected to an AM16/32 multiplexer and CR10X datalogger (Campbell Scientific, Logan, UT). Gravimetric water content measurements taken near the sensors at the end of each run confirmed calibration accuracy (data not shown). When VWC of the soil decreased below 10% in any tub, a signal was sent via a SDM16AC relay controller (Campbell Scientific, Logan, UT) which irrigated the tub with the appropriate treatment. Based on previous work (29), 10% VWC was the lowest level that did not cause stress to the turf.

The irrigation system applied approximately 33.8 oz. of water per minute at 30 psi. Pressure in the system was maintained with a bypass line and a pressure gauge. A total of 0.86 gal ft^{-2} of water was applied to the turf to bring the rootzone to field capacity. Runoff was prevented with an irrigation program of three one-minute cycles with five minutes of soaking in between cycles. This added an insignificant amount of organic matter to the turf systems (amounts ranged from 0.03% to 0.05%) compared to levels reported before beginning the experiments (0.4%). Drainage was observed through the gravel layer, and the rootzone was expected to have adequate levels of oxygen. Using a similar simulated green setup, Slavens (29) reported levels of oxygen between 19 and 21% which did not limit root growth.

Turf Management

Management of this turf system simulated the management of a golf course putting green. Turf was mowed at approximately 0.2 inches with electric grass shears twice each week and fertilized with 1 lb of N per $1000ft^2$ using a 24-6-12 granular fertilizer (Andersons, Golf Products, Maumee, OH). This also supplied 0.11 lbs of P per $1000ft^2$ and 0.41 lbs of K per $1000ft^2$ at planting. The fertilizer also contained 5.4% sulfur (S), 1% iron (Fe), 0.1% copper (Cu), 0.1% manganese (Mn), and 0.1% zinc (Zn). Weekly applications of



Spray emitters were used to apply overhead irrigation of the treatments to the simulated putting green turf.

KNO_3 (Fisher Scientific, Pittsburgh, PA) at 0.1 lb of N per 1000ft^2 were applied in 17 oz. of water. A topdressing of 0.1 inches of sand was applied every four weeks during the establishment period only.

A wetting agent, (Cascade, Precision Laboratories, Inc., Waukegan, IL) was applied to encourage uniform wetting of the soil profile (20) and to prevent turf loss during the experiment. Total soil moisture retention was not expected to be influenced by this wetting agent (19). Two applications of 8 oz. per 1000ft^2 using a CO_2 backpack sprayer at 40 psi were made according to label directions. The first application was at the beginning of the experiment, and the second was applied one week later. An additional wetting agent application was required during the third run of the experiment because low infiltration rates occurred in some treatments approximately two months into the study. Light irrigations with approximately 10 oz. of water to each tub occurred as needed throughout the experiment to prevent dry spots.

Air temperature was maintained at 75°F (day) and 60°F (night) throughout the study. High-pressure sodium lamps (1000 w) were used when light levels dropped below 300 W m^{-2} and day length was maintained at 12 hours. No pesticides were used prior to removing the sod from the putting green or during the study while in the greenhouse.

Evaluation of Treatments

Volumetric water content was measured every 10 minutes by the sensors. Because all three replications of a treatment did not dry down to 10% VWC at the same rate, the irrigation events occurred on different days. Thus, all VWC means on all days could not be analyzed. This included the days 20-22 in Run 1, days 13-22 in Run 2, and days 15-19 in Run 3. Additionally, the number of days between irrigation (irrigation interval) were analyzed. No water repellency tests were performed.

Leaf tissue was collected during each mowing with a hand-held vacuum, bagged, oven-dried at 176° F for at least 24 hours, bulked over the length of each run, and weighed. Leaf tissue was collected from each tub and analyzed for elemental concentration prior to each experimental run and the end of each run. Root length and dry mass measurements were made at the end of each run. Root length in each tub was measured in six cores from the center of the sod using a 12 in. long soil probe with a 0.4 in. inside diameter. Root length was determined from the first visible, attached root and measured from the crown. After measuring root length, cores were washed, and leaf tissue was cut from the roots at the crown. The leaf (shoot) and root samples were bagged, oven-dried at 176° F for two days and weighed.

RESULTS

Water Retention and Irrigation Frequency

Statistical analysis of VWC in the greens was complicated by the fact that tubs dried out at different rates (Figure 1). Citric acid-treated plots contained significantly more water on several days, and on other days, the control contained significantly more water (Figure 1). It is unclear why these differences occurred. Because of trends in VWC among the treatments and limitations of analyzing VWC data later in each irrigation interval, comparisons among treatments are best illustrated by the irrigation frequency analysis.

The period between irrigations was significantly influenced by the organic acid treatments (Table 1). Citric acid- and tannic acid-treated plots (13 days), along with the control (12 days) required less frequent irrigation than humic acid-treated plots (10 days). In Run 1, most tubs reached 10% VWC around day 20-22, however humic acid treated plots reached 10% VWC around day 15 (Figure 1a). By comparison, most tubs required irrigation around day 15-22 in Run 2 and day 11-19 in Run 3, with humic acid treated plots routinely drying out more quickly (Figure 1b, 1c).

Humic substances may have the potential

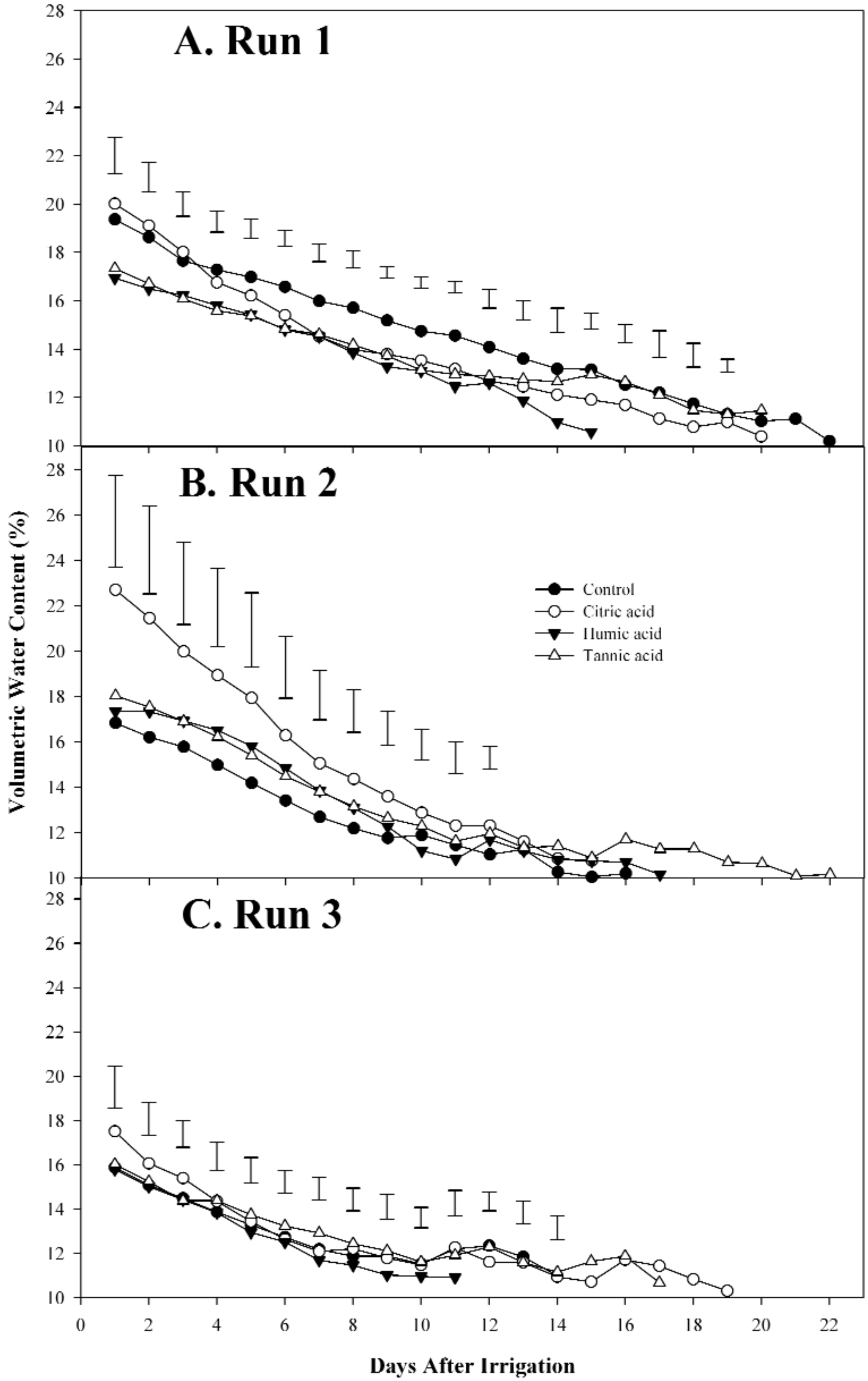


Figure 1. Volumetric water content of organic acid treatments following an irrigation event for Runs 1 (A), 2 (B), and 3 (C) in simulated sand-based putting greens. Bars indicate LSDs (P=0.05) for treatment comparisons at a given day. Days without bars were not analyzed because some treatments had only one mean.

Treatment	Irrigation Frequency	Tissue Biomass	Shoot Mass	Root Mass	Root Length	Root:Shoot Ratio
	days	....	g	....	cm	
Citric acid	13.16 a†	15.49 a	0.33 a	0.89 a	17.56 b	3.25 a
Tannic acid	12.82 a	16.57 a	0.31 a	0.94 a	18.28 b	3.87 a
Humic acid	10.15 b	17.10 a	0.23 a	1.02 a	21.52 a	4.34 a
Control	12.37 a	16.91 a	0.31 a	0.77 a	17.72 b	3.03 a

† Means within same column with same letter are not different significantly at P=0.05.

Table 1. Effect of organic acid application on irrigation frequency, and shoot and root growth of creeping bentgrass grown in simulated sand-based putting greens.

to reduce soil water holding capacity by adsorbing to and enhancing the water repellency of surface soil layers (35). Hydrophobic soil is found particularly in the upper 2 inches of the profile (32), and although preferential flow was not measured in our study, preferential flow patterns, or fingering (3, 4), may have developed in the sand in the same way as those reported in other simulated greens (25). Hydrophobic surface coatings have a greater impact on soil particles with smaller surface area-making sandy soils more susceptible than loam or clay soils (36). Similar results of decreased water holding capacity were observed on a research putting green where the application of humic acid significantly decreased the VWC of the sand even with the use of a wetting agent (34).

Nutrient Uptake

Phosphorus uptake was not influenced by the treatments (Table 2), but several other tissue nutrient levels were significantly affected, including potassium (K), calcium (Ca), copper (Cu), zinc (Zn), manganese (Mn), and sodium (Na) (Table 2). It was not clear what mechanism was responsible for these effects, but they may relate to the chelating properties or functional group content of the organic acids used. Addition of organic acids may not have improved uptake of P because grasses are already efficient at obtaining P (7). In fact, creeping bentgrass has been reported to obtain adequate amounts of P even at very low soil P concentrations (16).

Plant Growth

Both above ground biomass measurements were not significantly influenced by the treatments, but root length was significantly influenced by the treatments (Table 1). By the end of the experiment, root length in tubs irrigated with humic acid increased from 5 in. to 8.5 in. - significantly longer than roots in the other treatments (Table 1). However, neither root dry mass nor root:shoot ratios were significantly influenced by the treatments (Table 1).

Increased rooting with application of humic acid was found on Kentucky bluegrass (40) tall fescue (28) and other crop plants (1, 27), but results on creeping bentgrass have been variable. Root growth was enhanced on creeping bentgrass after treatment with humic acid (15, 41), while others showed no increases (11, 37). Liu et al. (21), report that humic acid had no effect on root re-growth, and actually reduced root length at low levels, although 400 mg humic acid L^{-1} visually produced more developed roots.

Cooper et al. (9) observed no overall differences of root length with five different humic acid materials applied to foliage, but incorporation of granular humic acid into the rootzone produced significantly longer roots and greater root mass deeper in the rootzone. In our study, the deeper root growth in humic acid treated tubs (Table 1) may have been caused by the lower soil water content. Additionally, this root distribution may have influenced the P uptake of creeping bentgrass. Soil chemical processes between Ca in

Treatment	P	K	Ca	Mg	S	Fe	Cu	Zn	Mn	Na
	%					mg/kg				
Control	0.38 a†	2.59 a	0.50 ab	0.28 a	0.38 a	138 a	12 b	33 b	30 c	575 ab
Humic acid	0.36 a	2.45 ab	0.47 b	0.26 a	0.35 a	196 a	13 b	35 b	42 bc	1185 a
Citric acid	0.36 a	2.64 a	0.51 ab	0.26 a	0.34 a	146 a	14 b	35 b	56 b	331 b
Tannic acid	0.34 a	2.20 b	0.56 a	0.28 a	0.35 a	205 a	17 a	42 a	271 a	46 b

† Means within same column with same letter are not different significantly at P=0.05.

Table 2. Effect of organic acid application on tissue nutrient concentration of creeping bentgrass grown in simulated sand-based putting greens.

the calcareous sand and P applied at establishment may have limited P availability to roots developing deeper in the rootzone.

Conclusions

The application of humic acid to simulated calcareous sand putting greens decreased water retention relative to the control that received only water. This resulted in the need for more frequent irrigation. The addition of humic acid did not have a significant effect on the P uptake by creeping bentgrass. Application of citric or tannic acid to the turf resulted in significantly higher tissue concentrations of several other nutrients, but humic acid did not affect uptake of any nutrients compared to the control. Humic acid increased root length, however the mechanism responsible for this increase is not fully understood and needs further study. Although humic acid may provide other benefits to turf, using it to amend putting greens specifically to improve water retention and nutrient acquisition is not justified by our findings.

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