IRON FERTILIZATION ON CREEPING BENTGRASS GOLF GREENS. II. EFFECTS ON ROOT GROWTH, WATER USE, AND WATER STRESS[1]

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ABSTRACT

Creeping bentgrass (Agrostis palustris Huds.) golf greens frequently suffer summer drought and heat stress, particularly when grown in hot, humid areas such as the Southeastern United States. This study was initiated to determine the effect of Fe on Fe-sufficient bentgrass root growth and response to water stress. Ferrous sulfate ($FeSO_4 \cdot 7H_2O$), Lawn-Plex, (Fe phosphate-citrate), and Sequestrene 330 (sodium ferric diethylenetriaminepent-acetate) were applied to an experimental golf green at 1.12 kg $Fe \cdot ha^{-1}$ per month over a 17 month period. Plots were maintained under two irrigation regimes (1.3 or 1.0 cm every other day in summer, and 1.0 or 0.8 cm every other day in other seasons). Root growth, water use, canopy temperature, water potential, and resistance to wilt were monitored during four dry-down periods (July, Aug., Oct. 1987; and June 1988). All Fe treatments resulted in root growth (weight and length) equal to, or less than the control. Lawn-Plex tended to reduce rooting most often, yet had a higher water use than the control and other treatments. Iron had an infrequent, minor effect on other stress indicators (canopy temperature and water potential). Different irrigation levels had little influence on

bentgrass response to Fe. Although Fe fertilizers reduced fall wilt, under the conditions of this study, Fe had an insignificant influence on bentgrass summer-stress tolerance. Since the responses were few and somewhat varied between Fe sources, reported Fe effects are probably due to a combination of Fe and carrier.

The smooth, dense canopy of creeping bentgrass (Agrostis palustris Huds.) makes it a highly desirable surface for golf greens. Recently, demand and use of bentgrass greens has increased in the mid to northern areas of the Southeastern United States. Unfortunately, the cool-season species adapts better to more temperate climates. Close mowing and frequent use subject bentgrass to severe stress, particularly in summer months.

Iron has been applied to improve turfgrass color and enhances turfgrass color under Fe-deficient (Deal and Engel, 1965; Ludwick, 1973; McCaslin and Watson, 1977; Minner and Butler, 1984; Seitz and Kneebone, 1970) and Fe-sufficient conditions (Carrow, 1983; Schmidt and Snyder 1984; Snyder and Schmidt 1974; and Yust et al., 1984). Snyder and Schmidt (1974) found Fe applications alleviated the summer yellowing often associated with bentgrass greens, which frequently occurs throughout the United States.

Limited information exists pertaining to the effects of Fe on turfgrass root growth. Under calcareous conditions, Deal and Engel (1965), and Horst (1984) found Fe enhanced rooting of Kentucky bluegrass (Poa pratensis L.) and bermudagrass (Cynodon dactylon [L.] Pers.), respectively. Schmidt (1986) reported Fe increased rooting of newly sodded Kentucky bluegrass. Under Fe-sufficient conditions, Snyder and Schmidt (1974) found Fe increased bentgrass summer root weight under high N when using Seq

330. Similar results were observed in a growth chamber study simulating spring through summer conditions (Schmidt and Snyder, 1984). Glinski et al. (1989) found Fe fertilizers had no effect on harvested root length or weight of bentgrass; yet organic sources (Lawn-Plex and Seq 330) tended to increase root length shortly after Fe application.

In addition, or as a result of effects on shoot and root growth, Fe may improve bentgrass drought tolerance. Snyder and Schmidt (1974) found Fe reduced bentgrass winter desiccation in Virginia. Schmidt (1986) reported Fe applications on Kentucky bluegrass grown on non-calcareous soils increased turfgrass rooting 44 to 50% and improved tolerance to waterloss of new sod. This work has increased interest in Fe as a means of improving bentgrass drought tolerance on established turf.

Currently, limited information exists to explain the reported ability of Fe to improve drought tolerance under Fe-sufficient conditions. Possibly, Fe could alter drought tolerance through its effects on shoot and/or root growth. The effect on shoot growth could influence drought tolerance by altering transpiration. Sharma and Sharma (1987), found Fe had a direct, decreasing effect on transpiration of cauliflower (Brassica oleracea L.) and attributed this response to larger stomatal opening and lower diffusive resistance. Low Fe also reduced leaf thickness and enhanced wilt. Indirectly, Fe could reduce transpiration through its ability to improve turfgrass color. Iron could increase root growth via increasing root carbohydrate utilization by reducing the percentage of carbohydrates used by shoots (decrease shoot growth), or increasing photosynthesis and carbohydrate production, as found by Schmidt and Snyder (1984). Likewise, Fe's ability reduce the necessity of N applications could allow greater root growth--frequent N application is often associated with low root production (Madison, 1962). Overall, the increased root growth might provide better water extracting potential and enhanced drought tolerance.

A companion study (Glinski, et al., 1988b) discloses summer shoot responses to Fe. In the current research, our objective was to evaluate the influence of Fe on water stress response of creeping bentgrass, particularly in the summer months. Iron and water stress relationships were determined by studying Fe-induced responses of root growth, water extraction, canopy temperature, and leaf water potential.

MATERIALS AND METHODS

The research was conducted on a two-year-old 'Penncross' creeping bentgrass putting green at the Georgia Experiment Station, Griffin, GA. Green construction followed United States Golf Association specifications (Ferguson, 1965) and encompassed an area of 673 m^2 containing 24 separate plots (4.6 m x 4.6 m each). Maintenance practices are described in a previous paper (Glinski, et al., 1989b).

Experimental design consisted of a 4 x 2 factorial (4 Fe carriers x 2 irrigation levels) in a completely randomized block with three replications. Iron treatments included a control and three different Fe carriers: (a) iron sulfate (FS)--Fisher Analytical Reagent[1] $FeSO_4 \cdot 7H_2O$ (Fair Lawn, NJ), 20% Fe, 12% S; (b) Lawn-Plex (LP)--R.G.B Laboratories[1] Fe phosphate-citrate (Kansas City, MO), 8% Fe, 8% S; (c) Sequestrene 330 (Seq 330)--Ciba-Geigy[1] sodium ferric diethylenetriaminepentacetate (Greensboro, NC), 10% Fe. Treatments began Mar. 1987 and continued through June 1988. Iron was applied monthly at a rate of 1.12 kg $Fe \cdot ha^{-1}$. Applications were in the morning (before 1000 h), usually

[1] Mention of a product does not constitute endorsement or preference of the product over similar products.

in the presence of dew. Each plot contained a zone of four pop-up, 1/4-circle mist heads at the corners. Irrigation treatments were well watered (100%) and moderate water-stress (80%). Well watered irrigation rates were derived from empirical data; moderate water stress rates represented 80% of the well watered rates. Plots received 1.3 (100%) or 1.0 (80%) cm of water every other day during the summer (19 July-20 Sept 1987), and 1.0 or 0.8 cm of water every other day in the non-summer months.

During the study, plots were subjected to four drought-stress periods: July, Aug., Sept. 1987, and June 1988. The evening before stress initiation, plots received normal mowing and irrigation. During the stress periods, several stress response indicators were monitored. Measurements included canopy temperature (CT), water use, leaf-water potential (Aug.), and turfgrass appearance (visual quality, color, and amount of wilt). As the turfgrass approached severe wilt (usually in the afternoon of the third stress day), plots were irrigated, ending the drought stress period. After the period, root samples were collected.

Canopy temperatures were measured four times each day (around 1000, 1200, 1500, 1800 h) with an Everest Model 110 infra-red thermometer (Everest Interscience, Tustin CA). Average plot temperatures were determined under clear skies from measurements taken from two directions. Immediately after measuring CT, air temperatures were recorded. In order to decrease the influence of time between the first and last readings, and to highlight temperature changes, data was analyzed as CT minus air temperature.

Water use, determined by monitoring soil moisture, was measured by time domain reflectrometry (IRAMS Model, Soil Moisture Equip. Corp., Santa Barbara, CA). Prior to drought-stress initiation, two groups of stainless steel rods (a group consisting of a 14 and 25 cm set) were inserted at 60° angles (relative to ground) in each plot to depths of 10 and 20 cm, respectively. Measurements were made three times a day (0800, 1200 and 1700 h). Water use equaled the difference between initial and subsequent readings. These values yielded water use per day, per dry-down period, and cumulative water use.

Immediately prior to the end of a stress period, plot appearance was evaluated. Wilt evaluation entailed multiplying the area of wilt by the severity of wilt (1=no wilt, 9=severe wilt). At the same time, plots were rated for turfgrass quality (9=ideal color, density, uniformity and texture; 1=no live turf) and color (9=dark green, 1=no green).

During the Aug. 1987 stress period, relative leaf-water potential was measured with a Model J-14 Hydraulic Press (Decagon Devises, Pullman WA). Daily measurements (three per plot) were made at 1300 h on complete shoot systems. Initially, relative leaf-water potential was recorded at the first appearance of stomatal water exudate (under 20X magnifying lens). This technique consumed an unexpected amount of time (approximately 5 min per plot). In order to decrease measurement time, water potential was later recorded when the tissue appeared water soaked. Campbell and Brewster (1975) found this later technique to agree best with pressure bomb and leaf hygrometer results.

Root growth was characterized by root weight, length, and length per unit weight. Five (six in July 1987 and June 1988) soil cores (3.175 cm dia, 21.6 cm deep) were removed from a quadrant of each plot--a different quadrant for each stress period. After removing the top 1.3 cm (verdure and thatch), the cores were cut into two 10 cm sections. The upper sections (0-10 cm) were grouped together, as were the lower (11-20 cm). Cores were washed by agitation on a 1.0 (18 mesh) screen. Hand cleaning removed organic matter. Root length was determined by the root intercept method and Newman's equation (Newman, 1966). Due to the large volume of roots, four sub-samples were measured per core. These sub-samples were grouped (within a plot) and dried (80°C, 24 h) along with bulk samples. Lengths of bulk samples were interpolated from weights and lengths of sub-samples. Root growth (weight, length and length per unit weight) was analyzed at 0-10, 11-20, and 0-20 cm depths.

Data was analyzed using Statistical Analysis Systems procedures for correlation and GLM (SAS Institute, 1982) with a partitioning of sum of squares into main effects and interactions with a significant F-test of 10%. Selected single-degree of freedom contrasts were made on all data.

RESULTS AND DISCUSSION

Root Growth. In this study, Fe carriers did not increase root growth, but maintained root growth (weight and length) equal to, or less than the control. Root growth was unaffected by Fe carrier x irrigation interactions.

In early summer (July 1987 and June 1988), Fe did not affect root growth (Tables 1 & 2). Although statistically equivalent, the control tended to maintain an average RLD at both depths greater than any Fe treatment. In late summer (Aug.), FS had 22% lower RLD than the control at 0-10 cm (Table 3). Seq 330 and LP appeared to have a lower (not significantly) RLD than the control at both depths.

In fall (Oct.), Fe carriers had their most significant effect on root growth (Table 4). All Fe sources yielded less total growth than the control; the most dramatic differences appeared as weight. Total root weights (0-20 cm) were 17, 27, and 25% less than the control for FS, LP, and Seq 330, respectively. Root length density in the 11-20 cm zone was reduced 31% by FS, while unaffected in the 0-10 cm depth. Lawn-Plex treated turf exhibited reduced RLD at 0-10 cm (26%) and 11-20 cm (28%) relative to the control, while Seq 330 significantly reduced RLD by 21% in the surface 10 cm. Thus, Fe treatments did not enhance rooting and actually seemed to result in less root growth into mid-fall.

Seasonal patterns in root weight and RLD can be determined by comparing data from treatments 1-4. Using the control treatment data, surface (0-10 cm) root weights for July, Aug. and Oct. 1987 and June 1988 were 1931, 1876, 1509, and 1943 $mg \cdot 100\ cm^{-2}$, respectively; at 11-20 cm they were 458, 319, 242, and 287 $mg \cdot 100\ cm^{-2}$. Similar comparisons at 0-10 cm, using RLD instead of weight, in July, Aug., and Oct. 1987 and June 1988 were 47.3, 52.3, 42.6, and 51.1 $cm \cdot cm^{-3}$, respectively. These data suggested root weights declined from July to Aug., while RLD actually increased, apparently via smaller, thinner roots. From Aug. to Oct. root weights and RLD decreased dramatically at both depths. Expansion of the root system of this cool-season grass did not occur until after the Oct. sampling date. Root distribution by depth varied with the season, but based on weight, the surface 0-10 cm contained 81 to 87% of the total root mass.

Bentgrass RLD values exceed those reported for other agronomic crops (corn=0.01-0.45 $cm \cdot cm^{-3}$; soybean=0.02-0.50 $cm \cdot cm^{-3}$; barley=0.02-1.45 $cm \cdot cm^{-3}$)(Dwyer et al., 1988). Although values in this study nearly tripled bentgrass rooting found in a greenhouse study (Glinski et al., 1989), values from both studies are in relative agreement. Since the growing media contained a very high sand content, the unsaturated hydraulic conductivity would be low; high RLD should be beneficial in high evaporative demand and low hydraulic conductivity situations as a means of providing adequate water for the plant.

In addition to root length and weight, root growth was evaluated in terms of length per unit weight (RL/W)--a parameter that seems to reflect root diameter and/or density. Since no statistical Fe treatment differences occurred in RL/W, data were omitted; however, values suggest FS may influence RL/W since values at the 11-20 cm depth were 10 to 18% greater than the control on three dates. Other Fe carriers exhibited no significant trend differences from the control. Values of RL/W ranged from 230 to 341 $m \cdot g^{-1}$ with the surface values averaging 267 $m \cdot g^{-1}$ and the lower zone averaging 312 $m \cdot g^{-1}$. Values were highest in Aug. and least in July. In a greenhouse study, Glinski et al. (1989a) found higher values (470 m·g, average), and note LP tended to decrease thickness while FS and Seq 330 had no effect.

Irrigation treatments had a significant effect on root measurements only in Aug., (Table 3). Relative to the 100% irrigation regime, irrigation at 80% caused surface root weight and RLD to decline by 16 and 17%, respectively. Since the irrigation treatments resulted in few differences in rooting and all other measurements except color, the bentgrass apparently received sufficient water even at the 80% regime. An exception may have been during the hot, dry period of Aug. when clipping yields were consistently lower for the 80% treatment (Glinski et al., 1989b).

Under Fe-sufficient situations, Snyder and Schmidt (1974) researched the effects of fall through spring Fe fertilization on bentgrass golf greens. They (Snyder and Schmidt, 1974) found fall-winter (Oct. and Nov., or Oct., Nov., and Dec.) Fe applications increased spring root weight compared to treatments receiving a single application of only N in Oct. Spring (May-June) applications of Fe + N increased July root weight (relative to low N, high N, or low Fe + N). Also, they found increased frequency of Fe applications (fall-winter) tended to increase root growth (sampled in July) under a late fall N regime (no difference under a early spring N regime). They mention that Fe effects seem greatest during water-stress years. In a follow-up study, under greenhouse conditions, Schmidt and Snyder (1984), investigated the effects of Fe and Fe x irrigation interactions. They identified no interaction between Fe x irrigation, but noted a tendency for Seq 330 (FeDTPA) to increase root growth.

In a greenhouse study, Glinski et al. (1989) found Fe applications had no effect on total bentgrass root production. Yet, Seq 330 tended to produce the greatest root mass and length, while both Seq 330 and LP seemed to increase new root growth. FS appeared to hinder growth.

Our results differed from those of Snyder and Schmidt (1974) and Schmidt and Snyder (1984). Although several of the Fe application and root sampling dates do not coincide, our June-Aug. results should coincide with their fall-winter application and July sampling. Differences in climate, and/or levels of available soil Fe may contribute to the lack of agreement.

Current literature contains no explanation of how Fe may influence turfgrass root growth under Fe-sufficient growing conditions. An explanation could relate to color--darker color having denser chlorophyll and therefore producing more carbohydrates through photosynthesis (PS). Schmidt and Snyder (1984) provide some support for this possibility; under Fe-sufficient conditions, Fe increased PS under low N regime, while also increasing total nonsoluble carbohydrate content (TNC) under warm temperatures (27°C day/18°C night). However, under a high N regime, PS decreased.

In our study, the greatest color enhancement occurred in early fall through spring (Glinski et al., 1989b). Accordingly, root growth would be expected to increase during this time, especially since most rooting occurs at this time for bentgrass. Our results show Fe caused a general decrease in root growth and therefore the enhanced color (and presumably PS) did not promote rooting.

Iron's effect on root growth could also relate to altered shoot growth. During the fall, when Fe inhibited root growth to the greatest extent, Fe treatments tended to have a promoting effect on shoot growth (Glinski et al., 1989b). Lawn-Plex had the greatest increasing effect on shoot growth, and the greatest decreasing effect on root growth. Perhaps, this effect signifies increased carbohydrate utilization for shoot growth at the expense of root growth. Still, this would not explain the apparent reduced rooting in the spring since spring shoot growth was not effected by Fe treatment.

Recent evidence presented by Landsberg (1984) suggests plants respond to Fe deficiency by altering root morphology/anatomy (increased size and number of root rhizodermal cells and xylem parenchyma, stimulated lateral root induction, subapical swelling of cortex parenchyma cells and root hair formation). Although test plants were Strategy I type (non-graminaceous), and results were obtained under Fe-deficient conditions, this evidence shows a lack of Fe may alter root growth. Perhaps, applied Fe decreases a plants natural response to Fe uptake (i.e. altered root morphology in Strategy I plants), which may result in less roots.

<u>Water Use</u>. Water use refers to the total amount of water required for growth, plus the quantity transpired from the plant and evaporated from the soil (Beard, 1985). Since the quantity of water required for growth is negligible, water use is often viewed as evaporation + transpiration--usually referred to as evapotranspiration

(ET). In this study, plots presumably received equivalent precipitation, run-off and drainage; therefore, changes in soil moisture reflect ET, or water use.

General water use patterns indicated bentgrass used more water during the warm months than in Oct. (Tables 5-8). Based on the control, ET on the first day after irrigation ranged from 3.89 to 9.71 $mm \cdot d^{-1}$ and 5.52 to 7.06 $mm \cdot d^{-1}$ on the second day during the June to Aug. dates. In Oct. ET rates were 5.36 and 5.08 $mm \cdot d^{-1}$ for the first and second day after irrigation, respectively. In comparison, water consumption for other grasses at the same location were 3.05, 5.15, and 3.51 $mm \cdot d^{-1}$ for 'Tifway' bermudagrass, 'Meyer' zoysiagrass (Zoysia japonica), and common centipedegrass, respectively. In Aug. 1987 and June 1988, plots extracted near equivalent amounts from both depths, but slightly more from the surface 10 cm with 55 and 53%, respectively. In July and Oct. 1987 extraction occurred primarily from the lower (11-20 cm) depth (55 and 70%, respectively).

Cumulative, early summer (July 1987 and June 1988) water use data are reported in Fig. 1 and 2. No Fe treatment differences occurred in June 1988, but in July 1987, LP extracted more water than other treatments (19%>control, 15%>FS, and 26%>Seq 330). All other treatments used equivalent amounts of water. Most of the increased water use of LP originated on the second day (Table 6). In late summer (Aug.) all treatments used equivalent amounts of water over the 54 hours of the drought stress (Fig. 3). In fall, although significant only at a single time (32 h), LP appeared to use more water than other treatments, particularly FS (Fig. 4). These differences seem to originate from high water use on the first day and early the second day. Although not always significant, LP seemed to result in higher water extraction during stress periods.

Water extraction by depth and use per day further identify differences in water use. Early summer results correspond with those disclosed by cumulative evaluation. During the June 1988 stress period, all plots used equivalent amounts of water (use per period) (Table 5). During the July 1987 stress period LP plots used 19% more water than the control (Table 6). All differences occurred in the first 2 days of the period and were from the 11-20 cm zone. Other Fe treatments had similar water use as the control--on one occasion Seq 330 used significantly less [45%] water than the control (second day, 11-20 cm). No Fe carrier x irrigation interaction occurred.

Summer (Aug.) water use results are reported in Table 7. No Fe carrier x irrigation interaction occurred. All treatments had similar water use for the complete stress period, but on the second day, LP treated turf extracted more total (0-20 cm) and deep (11-20 cm) water than the control (13 and 22%, respectively) and Seq 330 (19 and 34%, respectively). Interestingly, from 0-20 cm, LP increased in water use from the first to second day by 14%, while the control and Seq 330 decreased (13 and 11%, respectively). On the third day, all Fe sources used more water from the 0-10 cm than the control.

During the Oct. 1987 stress period, an Fe carrier x irrigation occurred. During the period, Seq 330 used 39% more total (0-20 cm) water than the control under moderate water stress, while under well watered conditions, the control used 70% more deep (11-20 cm) water than FS. Although few period differences occurred, several daily differences were observed. Under well watered conditions, all plots used equivalent amounts of water on day 1. On the second day, LP used 35% more total water than the control, and extracted more water from 11-20 cm than all treatments (52%>control). On day 3, LP and FS extracted less deep, but more shallow water than the control. Under moderate water stress, FS used 69% more total water than the control during day 1 with most of the increase due to greater extraction from the surface depth. During day 2 and 3 all plots used similar quantities of water.

Plants that have low water use often avoid water stress (i.e. drought avoidance). Cowan (1965) demonstrated plants with low RLD may be better drought avoiders than plants with high RLD. During water stress periods, sparsely rooted plants are the first to show shoot stress. Consequently, the transpiration rate decreases, water is conserved, and soil water potential remains relatively high. Meanwhile, plants with extensive root systems transpire heavily due to the high water absorbing capacity. However, soil moisture eventually nears depletion, at which time plants wilt and eventually die. At the same time. plants with low RLD continue to slowly absorb water.

In contrast, we viewed high water use as beneficial under the conditions of this study: sandy soil media with low water holding capacity; sharp inflection in the moisture release curve; limited depth of root system; grass with high water use; and conditions requiring the turf to maintain turgor for wear resistance. A turf that absorbs water quickly would have better drought avoidance capabilities--the fact that few extraction differences occurred in the third day offers some support that low soil moisture controlled ET more than plant aspects late in the stress period. Also, it is important to note this was not a water conservation study. Water is readily available on golf greens which are normally irrigated every 1 to 2 days. The objective was to determine if Fe enhanced bentgrass ability to extract water for the first 1 to 2 days after an irrigation event, which could reflect enhanced summer-stress tolerance. Therefore, high, initial water use was considered beneficial.

Deep, prolific root systems are commonly considered to enhance water absorption (Beard, 1973). In this study, a poor correlation existed between water use and rooting. Water use tended to decrease as rooting increased, especially in June (r=-0.54, p=.07), July (r=-0.39, p=.06) and Aug. (r=-0.33, p=.11). In a similar study, Carrow et al. (1988) found water extraction of zoysiagrass (Zoysia japonica x Zoysia tenuifolia) roots in the 11-20 cm soil depths decreased as RLD increased when going from water stress to well irrigated conditions. Similarly, Shearman and Beard (1973) found a poor correlation (r=+0.48) between root organic matter and creeping bentgrass water use.

The unusually dense surface rooting of bentgrass may contribute to the poor correlation between roots and water use. The high RLD, especially between 0-10 cm, may cause soil water potential to limit water uptake more than the lack of roots. As RLD decreases with depth, water use may be limited by rooting. This is supported by results that show all differences in water use (per period) occurred between 11-20 or 0-20 cm. In addition, the vast majority (73%) of daily differences appeared between 11-20 and 0-20 cm.

The influence of deep rooting on water use introduces an important point. Although the majority of roots exist within the top 20 cm, work by Glinski et al. (1989) and personal observation in the University of Georgia rhizotron, show bentgrass roots may grow well below 20 cm. Since roots below 20 cm were not collected, correlations between root growth and stress responses (water use, CT, and wilt) may be misleading. These results imply that in studies investigating the influence of a factor (such as

Fe) on bentgrass total root growth, modest changes in surface 0-10 cm rooting may have little influence on plant water use. Substantial changes in surface rooting, or changes in deeper rooting (11-20 cm) may be required before observing effects on water use. Accordingly, genetic improvements of bentgrass rooting should be directed towards deeper rooting and/or higher RLD in the deep soil zone.

The very high RLD of bentgrass in the 0-10 cm zone appeared to cause an interesting phenomena during the 800 to 1100 h period when subsurface (i.e. 11-20 cm) soil moisture was adequate. As evaporative demand increased, a transient period occurred when TDR measurement of water content (soil and root water) revealed a net increase in water content in the 0-10 cm zone. Presumably, water uptake by the roots in the deeper profile and movement into the denser root mass of the surface 10 cm accounted for this net increase.

Another possible influence of roots on water use could relate to root morphology. Plots with higher water use may have had greater surface area, or thicker roots. Yet, morphology measurements (length of roots/gram of root) revealed no relationship between water use and root morphology (data not presented). Also, Fe could affect water use due to shoot responses: growth rate, density, color, canopy temperate...etc. Some of these factors will be briefly discussed in the remainder of this paper.

Canopy Temperature. Turfgrass responds to water stress in several manners. During early stages of stress, turfgrass plants close their stomata (Younger, 1985). This process, a form of drought avoidance, allows plants to maintain satisfactory internal water potential (sufficient for normal physiological and biochemical processes). Stomatal closure decreases transpiration--the flow of water through the soil-plant-air continuum. Since transpiration cools the plant, decreasing transpiration results in increased leaf temperature. In this manner, measurement of CT may indicate a degree of water stress. In our studies, general increases in temperature as drought stress periods increased, indicate CT reflected some degree of stress. Also, CT measurements of wilted areas which developed during stress periods, showed higher temperatures than 'normal' areas (5-10°C higher). Since these areas contained visible stress accompanied by higher canopy temperatures, it was assumed that as turf temperature increased, stress increased.

Canopy temperature data was gathered to support water use data; high water use causing low CT via evapotranspiration. Iron carriers caused scattered, non-uniform effects on CT (Fig. 5-8). In early summer (July 1987 and June 1988), LP and FS plots seemed to exhibit relatively warm temperatures, while Seq 330 plots possessed cool temperatures. Also, in the fall (Oct.), FS plots appear slightly warmer than other plots.

Several factors complicate CT interpretation: variable season effects, variable carrier effects, and lack of previous data. In attempts to clarify possible influencing factors, CT was correlated with water use, clipping yield and color. No correlation existed between temperature and water use (none better than r=.45, or significant below 10% level). Plots with faster growth rates could be expected to be slightly cooler due to increased leaf area for transpiration. All Aug. and Oct. (except one) correlations suggest increased clipping yields correspond with decreased CT. In Aug., several (30%) of the readings were significant (below 10% level), but with low r values (r=0.38-0.49).

Color could possibly affect canopy temperature; darker canopies emitting more infra-red (heat). Iron could increase chlorophyll content and maintain thyllakoid membrane structure, which should enhance radiation absorption between red and blue wavelengths. Although, July results appear insignificant, 30% of the results in Aug. and Oct. indicate darker plots had cooler temperatures (r=-0.41 and -0.76, respectively). Apparently, the lighter turf absorbed more incident radiation (excluding red to blue wavelengths) than the darker turf, and thus had a higher temperature.

Water Potential. Water stressed plants usually possess low water potentials (Kramer, 1983). In an attempt to evaluate the degree of water stress, leaf-water potential was measured by three methods (pressure bomb, frozen psychrometer samples and hydraulic press). The fine blades of bentgrass often limited successful, accurate measurement. Most consistent, and easily obtained results were with the hydraulic press. Hydraulic press results indicated that Fe may influence water potential (Table 9). On day 1, all Fe treatments had greater leaf-water potential than the control. On day 1 (near same time as water potential measurements) all Fe plots had a lower CT than the control (only LP significant) (Fig. 7), and average water use of the control exceeded the other treatments (Table 7). The higher CT may cause high transpiration, which may decrease leaf-water potential. Further research is necessary to define any definite relationships between possible positive Fe stress effects on water potential.

<u>Visual Shoot Responses</u>. Shoot response to water stress following drought stress periods was negligible in terms of color and quality (Table 10). Plots maintained similar status to those taken prior to dry down (data not shown). The most dramatic differences to stress response appeared as wilt (Table 10). In July and Aug. no treatment differences occurred. In Oct., control plots wilted more than Fe treatments. In June, under moderate water stress, the control and FS treatments appeared to exhibit more wilt than LP and Seq 330 plots. These latter results agree with Schmidt's opinion that Fe carrier effects appear more dramatic under stress conditions (especially Seq 330). The

seasonal results remain enigmatic. Iron delayed wilt in Oct., but not in June, July, or Aug. Several factors could influence wilt: CT, water use, and root growth. However, none of these appeared to explain the Oct. wilt responses when comparing control versus Fe treatment data.

Previous researchers found Fe inhibited bentgrass winter desiccation and promoted root growth (Schmidt and Snyder, 1974; Snyder and Schmidt, 1984). Based on these findings, it has been suggested Fe enhances water stress tolerance of creeping bentgrass golf greens. Following these suggestions, golf course superintendents frequently apply Fe to greens to enhance water stress tolerance.

Overall, combining the results of this study with those of an earlier, companion study (Glinski et al., 1989), it appears Fe can improve summer color of Fe-sufficient bentgrass, but the degree of color response in summer is less than at other times of year. All Fe treatments resulted in rooting equal to or less than the control, while only LP provided better water extraction. Iron relationships to drought stress as measured by canopy temperature and leaf-water potential were not strong. The magnitude of Fe treatment effects on water use are less than those expected for N and K. Thus, growers should concentrate on N and K as nutrients with a greater influence on summer stress performance of bentgrass.

The fact that response can vary with Fe carrier (i.e. in this study only LP enhanced water uptake; in the companion study only Seq 330 reduced verdure and sometimes clipping yields), indicates a factor other than Fe influences some of the responses. In studies with only one Fe source, the results may be caused by other chemicals in the source rather than Fe. Care should be taken in attributing responses to Fe as a nutrient.

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Table 1. July (1987) root growth of a bentgrass golf green as affected by monthly applications of various Fe fertilizers.

Treatment		root weight			root length density	
		depth, cm				
Fe[z]	Irrigation[y]	0-10	11-20	0-20	0-10	11-20
		--- mg·100cm^{-2} ---			- cm·cm^{-3} -	
None	100%	2152	512	2664	50.9	13.6
None	80	1711	405	2116	43.8	9.6
Avg		1931	458	2390	47.3	11.6
$FeSO_4$	100	1512	393	1905	35.5	8.1
$FeSO_4$	80	2120	481	2601	51.0	11.6
Avg		1816	437	2253	43.3	9.7
Lawn-Plex	100	1802	444	2246	43.1	10.8
Lawn-Plex	80	1622	461	2083	40.6	11.1
Avg		1712	452	2164	41.9	10.9
Seq 330	100	2053	358	2411	49.8	7.3
Seq 330	80	1544	421	1965	45.1	10.8
Avg		1798	389	2188	47.4	9.1
Avg Irrigation						
	100	1880	427	2306	44.8	9.9
	80	1749	442	1965	45.2	10.7
CV(%)		22.4	20.9	218.8	29.0	29.4
Statistical Significance[e]						
FeC (Fe carrier)		NS[x]	NS	NS	NS	NS
Irrigation (Irr)		NS	NS	NS	NS	NS
FeC x Irr		NS	NS	NS	NS	NS
Contrasts[w]						
None x $FeSO_4$		NS	NS	NS	NS	NS
None x Lawn-Plex		NS	NS	NS	NS	NS
None x Seq 330		NS	NS	NS	NS	NS

z Fe applied at 1.12 kg Fe·ha^{-1} a month.
y 100% = 0.99 cm water every 2 days.
x NS=not significant using F-Test at 10% level.
w Contrasts on average of irrigation regimes.

Table 2. Effect of Fe fertilizers on bentgrass root growth: June dry-down, 1988.

	root weight			root length density	
	depth, cm				
Treatment[zyx]	0-10	11-20	0-20	0-10	11-20
	$mg \cdot 100cm^{-2}$			$cm \cdot cm^{-3}$	
None	1943a	287a	2230a	51.1a	9.3a
$FeSO_4$	1557a	243a	1800a	40.6a	9.4a
Lawn-Plex	1962a	300a	2262a	48.5a	7.4a
Seq 330	1693a	251a	1945a	46.7a	7.6a
CV(%)	16.2	33.9	17.5	14.8	41.3

z Fe applied at 1.12 kg $Fe \cdot ha^{-1}$ a month.
y Column values followed by different letters differ at the 5% level, Duncan's multiple-range test.
x All treatments measured at 100% irrigation (0.99 cm of water every 2 days).

Table 3. August (1987) root growth of a bentgrass golf green as affected by monthly applications of various Fe fertilizers.

Treatment		root weight			root length density	
		------------- depth, cm			-------------	
Fe[z]	Irrigation[y]	0-10	11-20	0-20	0-10	11-20
		--- $mg\cdot 100cm^{-2}$ ---			- $cm\cdot cm^{-3}$ -	
None	100%	2077	370	1332	57.4	14.5
None	80	1676	269	1058	47.3	10.3
Avg		1876	319	1195	52.3	12.4
$FeSO_4$	100	1527	262	952	42.5	12.0
$FeSO_4$	80	1611	315	1300	39.5	10.0
Avg		1569	288	1126	41.0	11.0
Lawn-Plex	100	1886	264	1123	52.6	9.6
Lawn-Plex	80	1434	242	1041	36.6	8.4
Avg		1660	253	1082	44.6	9.0
Seq 330	100	1957	293	1205	50.6	8.7
Seq 330	80	1540	330	982	45.2	10.4
Avg		1748	312	1094	47.9	9.6
Irrigation Avg						
	100	1862	297	1080	50.8	11.2
	80	1565	289	927	42.1	9.7
CV(%)		21.8	36.0	23.4	21.3	30.9
Statistical Significance						
FeC (Fe carrier)		NS[x]	NS	NS	NS	NS
Irrigation (Irr)		.072	NS	NS	.052	NS
FeC x Irr		NS	NS	NS	NS	NS
Contrasts[w]						
None x $FeSO_4$		NS	NS	NS	.067	NS
None x Lawn-Plex		NS	NS	NS	NS	NS
None x Seq 330		NS	NS	NS	NS	NS

z Fe applied at 1.12 kg $Fe\cdot ha^{-1}$ a month.
y 100% = 0.99 cm water every 2 days.
x NS=not significant using F-Test at 10% level; 'number'=significant level using F-Test at 10% level.
w Contrasts on averages irrigation levels.

Table 4. October (1987) root growth of a bentgrass golf green as affected by monthly applications of various Fe fertilizers.

Treatment		root weight			root length density	
		depth, cm				
Fe[z]	Irrigation[y]	0-10	11-20	0-20	0-10	11-20
		--- mg·100cm^{-2} ---			- cm·cm^{-3} -	
None	100%	1427	256	1683	43.1	7.8
None	80	1590	227	1817	42.2	7.1
Avg		1509	242	1750	42.6	7.4
$FeSO_4$	100	1178	160	1338	37.9	5.7
$FeSO_4$	80	1426	135	1561	42.5	4.6
Avg		1302	147	1449	40.2	5.1
Lawn-Plex	100	1030	164	1194	29.4	5.4
Lawn-Plex	80	1183	162	1345	34.4	5.2
Avg		1106	163	1270	31.9	5.3
Seq 330	100	1191	176	1367	34.7	5.9
Seq 330	80	1092	176	1268	32.3	5.7
Avg		1142	176	1318	33.5	5.8
Irrigation Avg						
	100	1206	189	1395	36.3	6.2
	80	1323	175	1498	37.8	5.6
CV(%)		19.6	32.4	23.4	23.1	30.3
Statistical Significance						
FeC (Fe carrier)		.052[x]	.069	.028	NS	NS
Irrigation (Irr)		NS	NS	NS	NS	NS
FeC x Irr		NS	NS	NS	NS	NS
Contrasts[w]						
None x $FeSO_4$		NS	.015	.067	NS	.045
None x Lawn-Plex		.014	.037	.007	.048	.056
None x Seq 330		.022	.075	.013	.087	NS

z Fe applied at 1.12 kg Fe·ha^{-1} a month.
y 100% = 0.99 cm water every 2 days.
x NS=not significant using F-Test at 10% level;
'number'=significant level using F-Test at 10% level.
w Contrasts on averages of irrigation levels.

Table 5. Water consumption of a bentgrass golf green during an June 1988 drought stress period as affected by monthly fertilization with various Fe fertilizers.

Treatment[yx]	14 June[z]			15 June			16 June			14-16 June		
	depth, cm											
	0-10	11-20	0-20	0-10	11-20	0-20	0-10	11-20	0-20	0-10	11-20	0-20
	mm of extracted H_2O											
None	6.48a[w]	3.22a	9.71a	3.00ab	4.06a	7.06a	0.73a	1.82a	2.55a	10.21a	9.10a	19.31a
$FeSO_4$	7.13a	3.56a	10.69a	2.43b	6.50a	8.94a	0.96a	-1.76a	-0.80a	10.53a	8.30a	18.83a
Lawn-Plex	6.11a	4.78a	10.89a	2.95ab	4.52a	7.46a	0.57a	2.00a	2.58a	9.63a	11.30a	20.94a
Seq 330	6.48a	3.93a	10.42a	3.57a	2.67a	6.25a	0.93a	1.71a	2.64a	10.99a	8.32a	19.31a

z 14 and 15 June extraction measurements from 0800-1700; 16 June 0800-1300.
y Fe applied at 1.12 kg $Fe \cdot ha^{-1}$ a month.
x Column values followed by different letters differ at the 10% level, Duncan's multiple-range test.
w All treatments received 100% irrigation (0.99 cm water every 2 days).

Table 6. Water consumption of a bentgrass golf green during a July 1987 drought stress period as affected by monthly fertilization with various Fe fertilizers.

Treatment		17 July[z]			18 July			19 July			17-19 July		
		depth, cm											
Fe[y]	Irrigation[x]	0-10	11-20	0-20	0-10	11-20	0-20	0-10	11-20	0-20	0-10	11-20	0-20
		mm extracted water											
None	100%	1.64	2.52	4.17	1.79	3.94	5.73	0.48	0.38	0.85	3.91	6.83	10.74
None	80	2.06	1.56	3.62	2.37	3.76	6.13	0.54	1.09	1.63	4.97	6.40	11.38
Avg		1.85	2.04	3.89	2.08	3.85	5.93	0.51	0.73	1.24	4.44	6.62	11.06
$FeSO_4$	100	2.47	0.95	3.42	2.33	4.94	7.27	1.10	0.11	1.21	5.90	6.01	11.91
$FeSO_4$	80	1.17	2.42	3.59	2.40	4.16	6.56	1.39	-0.24	1.14	4.95	6.34	11.30
Avg		1.82	1.69	3.50	2.37	4.55	6.92	1.24	-0.06	1.18	5.43	6.17	11.60
Lawn-Plex	100	1.59	2.64	4.23	1.51	6.04	7.55	0.77	0.39	1.16	3.87	9.08	12.94
Lawn-Plex	80	1.74	3.33	5.08	2.51	5.35	7.86	1.15	0.37	1.53	5.40	9.06	14.46
Avg		1.67	2.99	4.66	2.01	5.70	7.70	0.96	0.38	1.34	4.63	9.07	13.70
Seq 330	100	1.52	2.37	3.89	2.74	1.57	4.29	1.27	-0.56	0.71	5.53	3.37	8.90
Seq 330	80	1.99	2.67	4.67	2.56	1.94	4.50	1.13	0.42	1.56	5.68	5.04	10.72
Avg		1.76	2.52	4.28	2.65	1.75	4.40	1.20	-0.07	1.13	5.60	4.20	9.81
Irrigation Avg													
	100	1.81	2.12	3.93	2.09	4.12	6.21	0.90	0.08	0.98	4.80	6.32	11.12
	80	1.74	2.50	4.24	2.46	3.80	6.26	1.05	0.41	1.46	5.25	6.71	11.96
CV(%)		44	35	26	29	41	26	77	492	65	24	42	22
Statistical Significance													
FeC (Fe carrier)		NS[w]	.071	NS	NS	.007	.020	NS	NS	NS	NS	.054	NS
Irrigation (Irr)		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
FeC x Irr		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Contrasts[v]													
None x $FeSO_4$		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
None x Lawn-Plex		NS	.063	NS	NS	.070	.082	NS	NS	NS	NS	NS	.096
None x Seq 330		NS	NS	NS	NS	.043	NS	NS	NS	NS	NS	NS	NS

z 17 and 18 July extraction measurements from 0700-1800 h; 19 July from 0700-1600 h.
y Fe applied at 1.12 kg $Fe \cdot ha^{-1}$ a month.
x 100% = 0.99 cm water every 2 days.
w NS=not significant using F-test at 10% level;'number'=significance using F-test at 10%.
v Contrast of irrigation averages within a treatment.

Table 7. Water consumption of a bentgrass golf green during a August 1987 drought stress period as affected by monthly fertilization with various Fe fertilizers.

Treatment		20 August[z]			21 August			22 August			20-22 August		
		depth, cm											
Fe[y]	Irrigation[x]	0-10	11-20	0-20	0-10	11-20	0-20	0-10	11-20	0-20	0-10	11-20	0-20
		mm extracted water											
None	100%	4.42	3.17	7.59	1.91	4.32	6.23	0.53	0.69	1.22	6.86	8.18	15.04
None	80	4.67	0.47	5.15	1.74	3.07	4.82	0.57	0.31	0.88	6.99	3.85	10.84
Avg		4.54	1.82	6.37	1.83	3.69	5.52	0.55	0.50	1.05	6.92	6.02	12.94
$FeSO_4$	100	6.10	0.37	6.47	1.30	5.77	7.07	1.31	-0.22	1.08	8.70	5.92	14.62
$FeSO_4$	80	4.91	1.25	6.16	1.96	3.65	5.62	1.00	0.08	1.08	7.87	4.99	12.86
Avg		5.50	0.81	6.31	1.63	4.71	6.34	1.15	-0.07	1.08	8.28	5.45	13.74
Lawn-Plex	100	3.86	2.07	5.93	1.54	5.13	6.67	1.41	0.66	2.07	6.81	7.86	14.67
Lawn-Plex	80	5.16	0.90	6.05	2.57	4.57	7.14	1.05	1.18	2.23	8.77	6.55	15.42
Avg		4.51	1.48	5.99	2.05	4.85	6.90	1.23	0.92	2.15	7.79	7.25	15.05
Seq 330	100	3.20	2.15	5.35	1.91	3.03	4.94	1.31	1.57	2.88	6.42	6.75	13.18
Seq 330	80	4.95	1.73	6.68	2.13	3.18	5.32	0.97	-0.20	0.78	8.06	4.71	12.77
Avg		4.07	1.94	6.01	2.02	3.11	5.13	1.14	0.69	1.83	7.24	5.73	12.97
Irrigation Avg													
	100	4.40	2.12	6.33	1.67	4.56	6.23	1.14	0.68	6.23	7.20	7.18	14.38
	80	4.92	2.50	6.01	2.10	3.62	5.72	0.90	0.34	5.72	7.92	5.05	12.97
CV(%)		36	139	23	33	27	16	50	301	95	30	55	21
Statistical Significance													
FeC (Fe carrier)		NS[w]	NS	NS	NS	.047	.027	NS	NS	NS	NS	NS	NS
Irrigation (Irr)		NS	NS	NS	NS	.055	NS	NS	NS	NS	NS	NS	NS
FeC x Irr		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Contrasts[v]													
None x $FeSO_4$		NS	NS	NS	NS	NS	NS	.061	NS	NS	NS	NS	NS
None x Lawn-Plex		NS	NS	NS	NS	.091	.027	.037	NS	NS	NS	NS	NS
None x Seq 330		NS	NS	NS	NS	NS	NS	.064	NS	NS	NS	NS	NS

z 20 and 21 August water extraction measurements from 0730-1700; August 22 from 0730-1130.
y Fe applied at 1.12 kg $Fe \cdot ha^{-1}$ a month.
x 100% = 0.99 cm water every 2 days.
w NS=not significant using F-test at 10% level;'number'=significance using F-test at 10%.
v Contrast of irrigation averages within a treatment.

Table 8. Water consumption of a bentgrass golf green during an October 1987 drought stress period as affected by monthly fertilization with various Fe fertilizers.

Treatment		17 October[z]			18 October			19 October[y]			17-19 October		
		depth, cm											
Fe[x]	Irrigation[w]	0-10	11-20	0-20	0-10	11-20	0-20	0-10	11-20	0-20	0-10	11-20	0-20
		mm extracted water											
None	100%	0.25	1.94	2.20	0.59	1.11	1.70	-0.25	1.17	0.92	0.59	4.22	4.82
None	80	0.24	0.51	0.74	0.51	1.22	1.73	0.24	0.17	0.41	0.98	1.90	2.88
Avg		0.24	1.22	1.47	0.55	1.16	1.72	-0.01	0.67	0.66	0.79	3.06	3.85
$FeSO_4$	100	0.05	0.29	0.35	0.51	1.15	1.65	0.90	-0.22	0.68	1.46	1.22	2.68
$FeSO_4$	80	0.90	1.48	2.37	-0.20	1.45	1.25	0.34	0.17	0.51	1.03	3.10	4.13
Avg		0.47	0.88	1.36	0.15	1.30	1.45	0.62	-0.02	0.59	1.25	2.16	3.41
Lawn-Plex	100	0.39	2.29	2.67	-0.06	2.29	2.23	0.44	0.40	0.84	0.77	4.98	5.75
Lawn-Plex	80	0.44	1.12	1.55	1.29	0.95	2.23	0.78	-0.41	0.37	2.50	1.66	4.16
Avg		0.41	1.70	2.11	0.61	1.62	2.23	0.61	0.00	0.61	1.63	3.32	4.95
Seq 330	100	0.46	1.17	1.63	1.04	1.03	2.07	-0.03	0.64	0.61	1.46	2.84	4.31
Seq 330	80	0.10	2.00	2.10	0.83	1.00	1.83	0.30	0.51	0.81	1.23	3.50	4.74
Avg		0.28	1.58	1.86	0.93	1.02	1.94	0.13	0.57	0.71	1.35	3.17	4.52
Irrigation Avg													
	100	0.29	1.42	1.71	0.52	1.39	1.91	0.29	0.52	0.76	1.07	3.32	4.39
	80	0.42	1.27	1.69	0.61	1.15	1.76	0.42	0.61	0.52	1.44	2.54	3.98
CV(%)	100	107	90	72	90	45	28	246	246	78	69	68	31

Statistical Significance												
FeC (Fe carrier)	NS[v]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Irrigation (Irr)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
FeC x Irr	.089	NS	.097	.021	.098	NS	NS	NS	NS	NS	.074	NS
Contrasts[u]												
100% Irrigation												
None x $FeSO_4$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
None x Lawn-Plex	NS	NS	NS	NS	.038	.027	NS	NS	NS	NS	NS	NS
None x Seq 330	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
80% Irrigation												
None x $FeSO_4$	.071	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
None x Lawn-Plex	NS	NS	NS	NS	NS	.027	NS	NS	NS	NS	NS	NS
None x Seq 330	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

z 17 and 18 October dry extraction measurements from 0900-1700; 19 October one reading (0900).
y 19 October only one soil moisture reading (wilt prohibited further readings).
x Fe applied at 1.12 kg $Fe \cdot ha^{-1}$ a month.
w 100% = 0.99 cm water every 2 days.
v NS=not significant using F-test at 10% level; 'number'=significance using F-test at 10%.
u Contrast of irrigation averages within a treatment.

Table 9. Water potential of bentgrass green shoots as affected by various Fe fertilizers during an Aug. drought stress period.

Treatment		Date (time of first reading)[z]			
Fe[y]	Irrigation[x]	20 Aug (1330)	21 Aug (1330)	21 Aug (1500)	22 Aug (1330)
		---- leaf water potential, MPa ----			
None	100	-0.224	-0.094	-0.774	-0.760
None	80	-0.202	-0.101	-0.908	-0.753
Avg		-0.213	-0.098	-0.841	-0.756
$FeSO_4$	100	-0.145	-0.093	-0.793	-0.702
$FeSO_4$	80	-0.170	-0.125	-0.859	-0.768
Avg		-0.157	-0.109	-0.826	-0.735
Lawn-Plex	100	-0.134	-0.112	-0.849	-0.754
Lawn-Plex	80	-0.153	-0.113	-0.779	-0.798
Avg		-0.143	-0.113	-0.814	-0.776
Seq 330	100	-0.133	-0.088	-0.790	-0.710
Seq 330	80	-0.139	-0.090	-0.852	-0.802
Avg		-0.136	-0.089	-0.821	-0.756
Irrigation Avg					
	100	-0.159	-0.097	-0.801	-0.732
	80	-0.166	-0.107	-0.849	-0.780
CV(%)		34.0	22.1	11.5	11.9
Statistical Significance					
FeC		NS[d]	NS	NS	NS
Irr		NS	NS	NS	NS
FeC x Irr		NS	NS	NS	NS
Contrasts•					
None x $FeSO_4$		.105	NS	NS	NS
None x Lawn-Plex		.045	NS	NS	NS
None x Seq 330		.030	NS	NS	NS

z Water potential for 20 and 21a Aug recorded when first water drop appeared from stomata; water potential for 21b and 22 Aug recorded when tissue appeared water soaked.
y Fe applied at 1.12 kg $Fe \cdot ha^{-1}$ a month.
x 100% = 0.99 cm water every 2 days.
w NS=not significant using F-test at 10% level; 'number'= significance using F-test at 10%.

Table 10. Shoot responses of a bentgrass golf green to drought stress periods in 1987 and 1988 and the influence of monthly applications of various Fe fertilizers on the stress reponse.

Treatment		Wilt[z]				Color				Quality			
		1987			1988	1987			1988	1987			1988
Fe Carrier[y]	Irr[x]	7-19	8-22	10-19	6-16	7-19	8-22	10-19	6-16	7-19	8-22	10-19	6-16
		9=severe, 1=no wilt				9=dark green, 1=no green				9=ideal, 1=no live turf			
None	100%	0.5	10.8	34.7	1.0	7.1	7.1	6.2	7.1	6.7	6.5	6.5	6.4
None	80	2.0	17.0	69.5	5.3	6.9	6.6	5.2	7.1	6.6	6.3	5.9	6.6
Avg		1.3	13.9	52.1	3.2	7.0	6.8	5.7	7.1	6.6	6.4	6.2	6.5
$FeSO_4$	100	0.3	12.8	3.2	0.0	7.7	7.4	6.9	7.8	7.1	6.5	6.7	7.4
$FeSO_4$	80	2.5	6.8	13.5	9.7	7.6	6.9	6.3	8.1	6.9	6.5	6.4	7.2
Avg		1.4	9.8	8.4	4.8	7.6	7.2	6.6	7.9	7.0	6.5	6.5	7.3
Lawn-Plex	100	0.7	7.7	0.1	3.3	7.5	7.4	6.6	7.5	6.8	6.4	6.9	6.9
Lawn-Plex	80	0.4	8.0	15.7	2.0	7.8	7.2	6.8	7.9	7.1	6.6	6.7	7.3
Avg		0.5	7.8	7.9	2.7	7.6	7.3	6.7	7.7	6.9	6.5	6.8	7.1
Seq 330	100	0.7	8.0	4.7	4.7	7.1	7.5	6.9	7.7	6.9	6.7	6.9	7.4
Seq 330	80	1.9	18.7	6.7	1.3	7.2	7.0	6.6	8.1	6.7	6.7	6.8	7.4
Avg		1.3	13.3	5.7	3.0	7.1	7.2	6.7	7.9	6.8	6.7	6.8	7.4
Irrigation Avg													
	100	0.5	9.8	10.6	2.2	7.3	7.4	6.6	7.5	6.9	6.5	6.7	7.0
	80	1.7	12.6	26.3	4.6	7.4	6.9	6.2	7.8	6.8	6.5	6.4	7.1
CV(%)		103	73	200	112	5.1	4.7	7.6	4.3	4.7	3.8	6.8	3.8
Statistical Significance													
FeC		NS[w]	NS	NS	NS	.03	NS	.01	.00	NS	NS	NS	.00
Irr		.03	NS	NS	NS	NS	.01	.07	.07	NS	NS	NS	NS
FeC x Irr		NS	NS	NS	.05	NS	NS	NS	NS	NS	NS	NS	NS
Contrasts[v]													
None x $FeSO_4$		NS	NS	.06	NS/NS[u]	.03	NS	.01	.01	.08	NS	NS	.01
None x LP		NS	NS	.06	NS/NS	.01	.03	.01	.01	NS	NS	.05	.01
None x Seq 330		NS	NS	.05	NS/NS	NS	.06	.01	.01	NS	.03	.03	.01

z On days 7-19, 8-22 and 10-19 severity of wilt (1=slight, 9=total) was multiplied by area (area) of wilt; on 6-16 ratings were based on severity alone.
y Fe carrier, Fe applied monthly, 1.12 kg Fe ha^{-1}.
x 100% irrigation (Irr)=0.99 cm water every 2 days.
w NS=not significant using F-test at 10% level; 'number'=significance using F-test at 10% level.
v Contrasts on average of irrigation levels, except where otherwise noted.
u 100% irrigation/80% irrigation.

Figure 1. Cumulative water use of a bentgrass green, July 1988: Average water use of well watered (100%) and water stressed (80%) treatments as influenced by various Fe fertilizers.

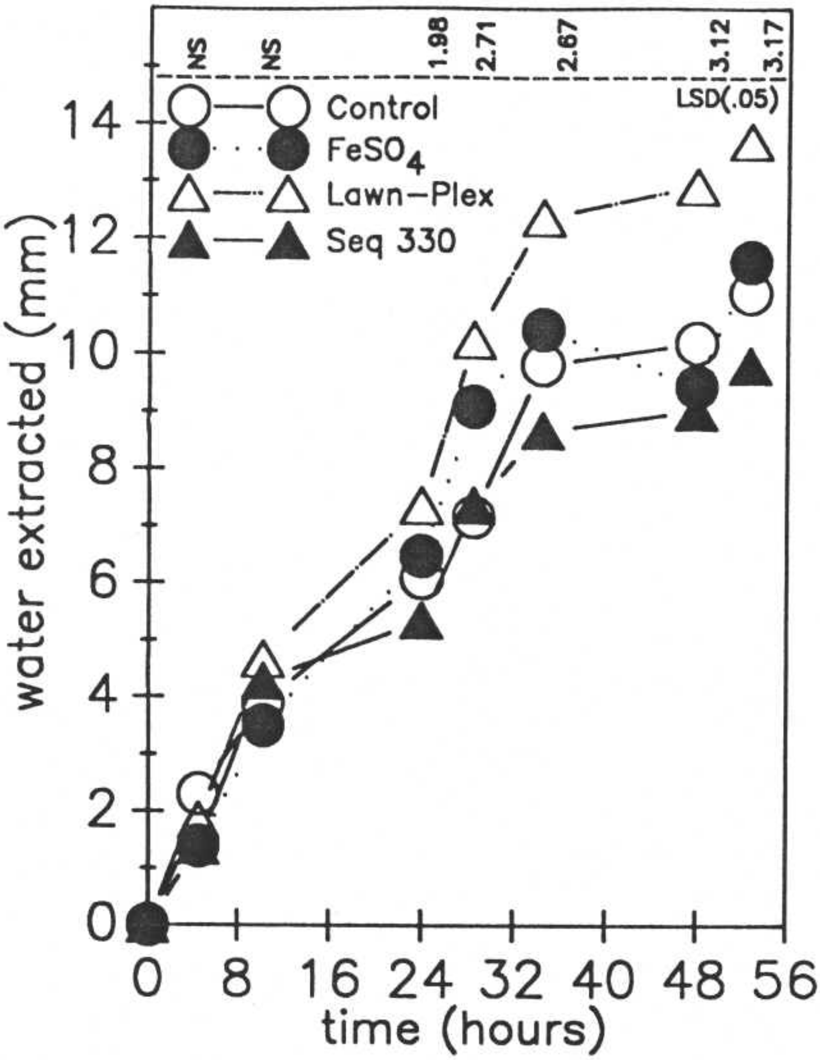
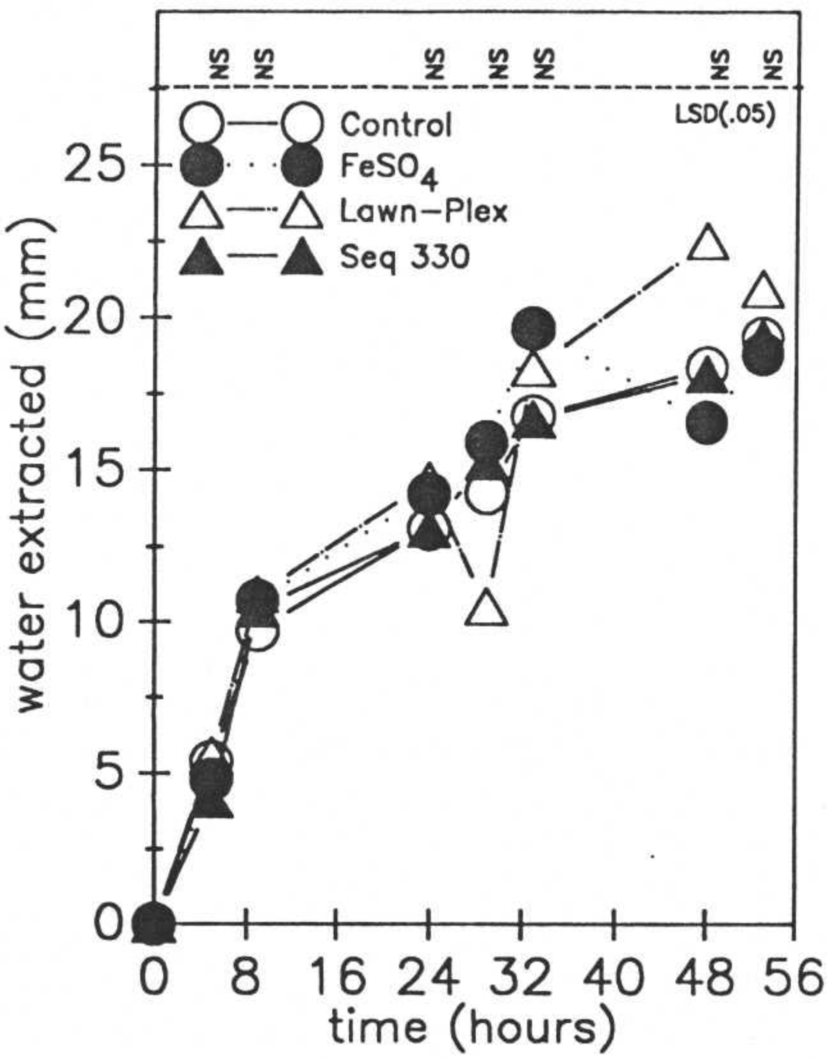

NS
NS
1.98
2.71
2.67
3.12
3.17
LSD(.05)
Control
FeSO4
Lawn-Plex
Seq 330
water extracted (mm)
0
2
4
6
8
10
12
14
0
8
16
24
32
40
48
56
time (hours)

Figure 2. Cumulative water use of a bentgrass green, June 1989: Water use of a well watered green as influenced by various Fe fertilizers.



NS NS NS NS NS NS NS
LSD(.05)
Control
$FeSO_4$
Lawn-Plex
Seq 330
water extracted (mm)
0
5
10
15
20
25
0 8 16 24 32 40 48 56
time (hours)

Figure 3. Cumulative water use of a bentgrass green, August 1988: Average water use of well watered (100%) and water stressed (80%) treatments as influenced by various Fe fertilizers.

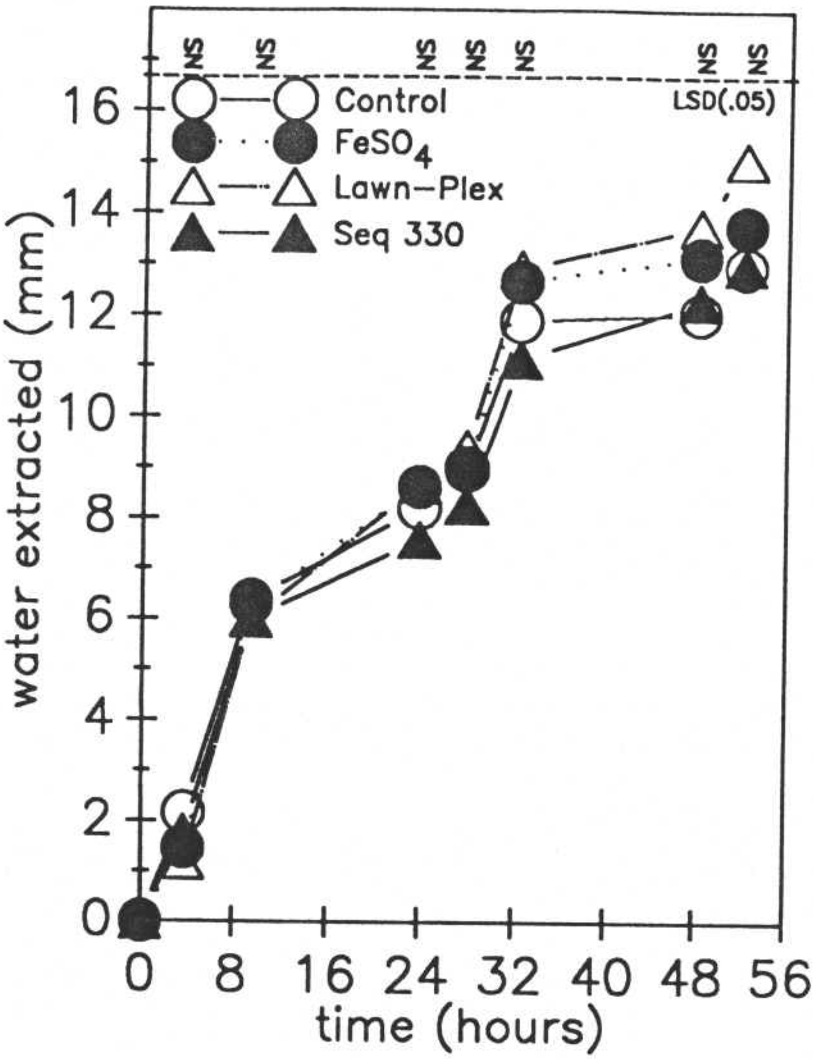

NS
NS
NS
NS
NS
NS
NS
LSD(.05)
Control
FeSO4
Lawn-Plex
Seq 330
water extracted (mm)
time (hours)
0
2
4
6
8
10
12
14
16
0
8
16
24
32
40
48
56

Figure 4. Cumulative water use of a bentgrass green, October 1988: Average water use of well watered (100%) and water stressed (80%) treatments as influenced by various Fe fertilizers.

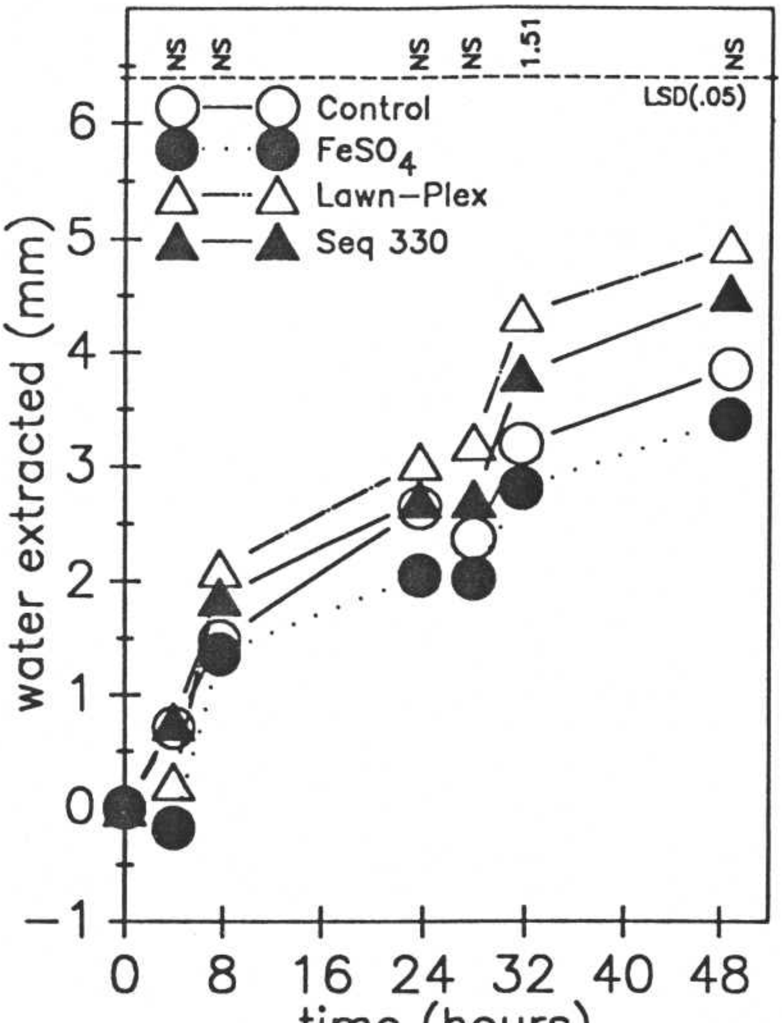

NS
NS
NS
NS
1.51
NS
LSD(.05)
Control
$FeSO_4$
Lawn-Plex
Seq 330
water extracted (mm)
6
5
4
3
2
1
0
−1
0
8
16
24
32
40
48
time (hours)

Figure 5. Canopy temperature minus air temperature on a bentgrass green, July 1988: Average temperature difference of well watered (100%) and water stressed (80%) treatments as influenced by various Fe fertilizers.

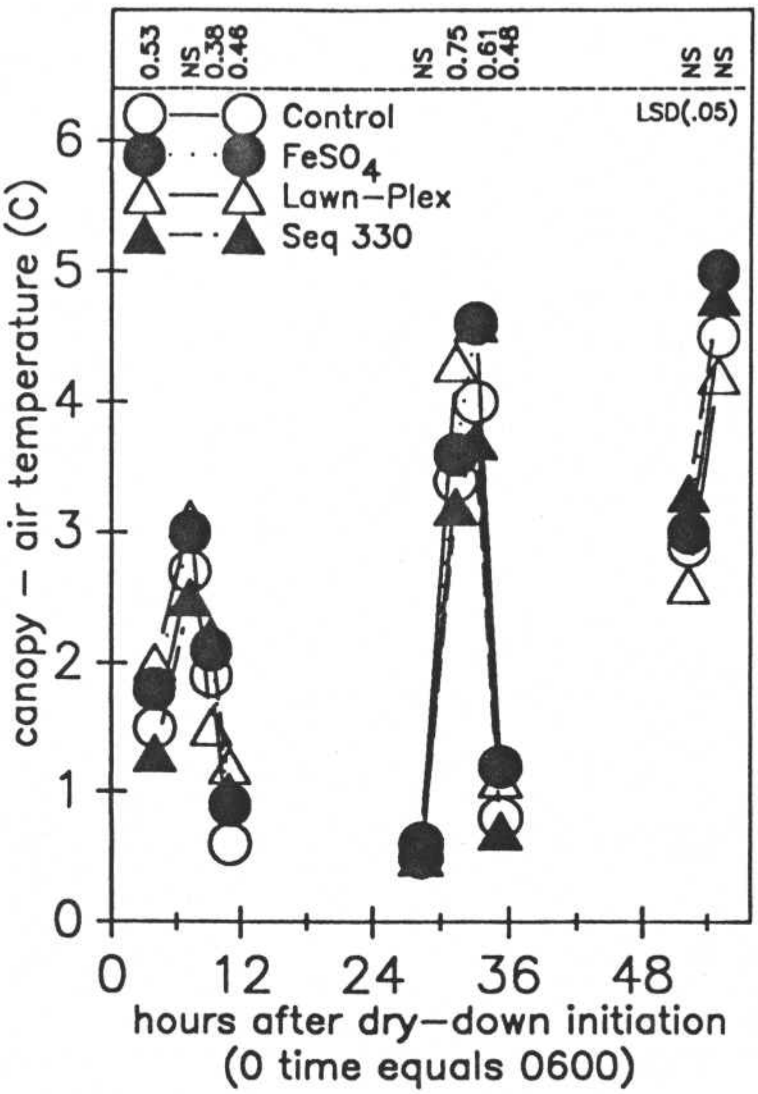

0.53
NS
0.38
0.46
NS
0.75
0.61
0.48
NS
NS
LSD(.05)
Control
FeSO4
Lawn-Plex
Seq 330
canopy - air temperature (C)
0
1
2
3
4
5
6
0
12
24
36
48
hours after dry-down initiation
(0 time equals 0600)

Figure 6. Canopy temperature minus air temperature on a bentgrass green, June 1989: Temperature difference of well watered (100%) treatments as influenced by various Fe fertilizers.

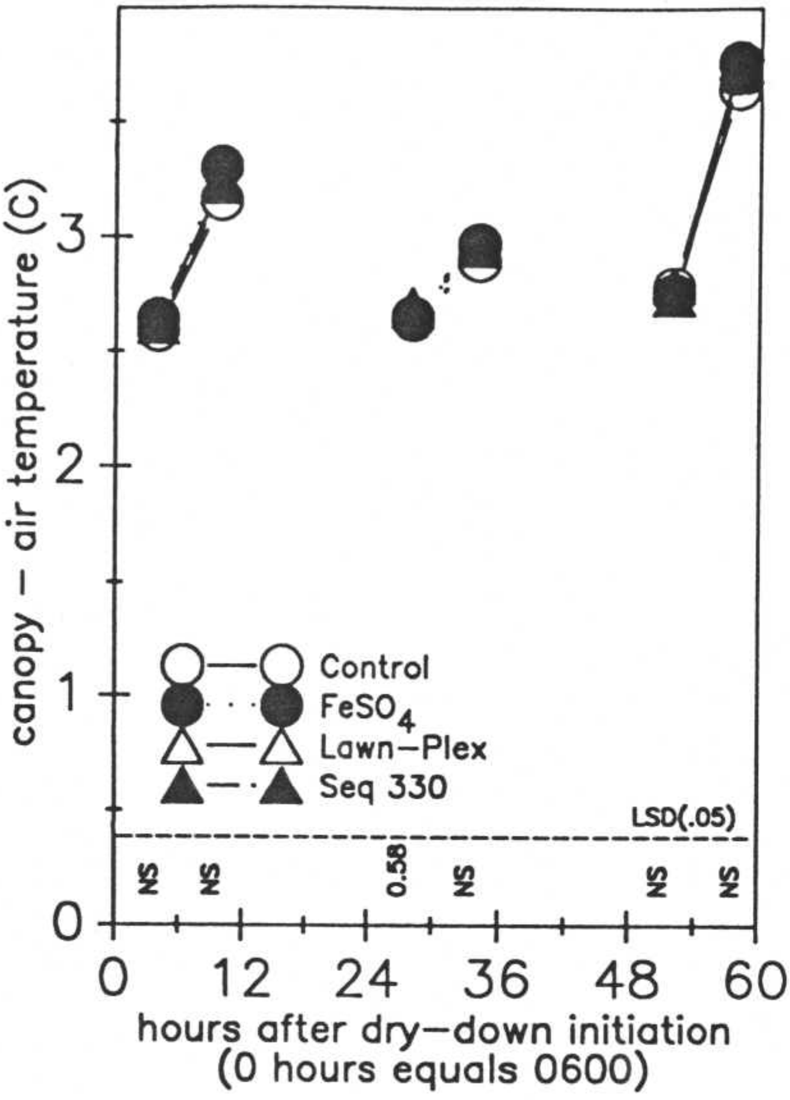

canopy - air temperature (C)
0
1
2
3
Control
FeSO4
Lawn-Plex
Seq 330
LSD(.05)
NS
NS
0.58
NS
NS
NS
0
12
24
36
48
60
hours after dry-down initiation
(0 hours equals 0600)

Figure 7. Canopy temperature minus air temperature on a bentgrass green, August 1988: Average temperature difference of well watered (100%) and water stressed (80%) treatments as influenced by various Fe fertilizers.

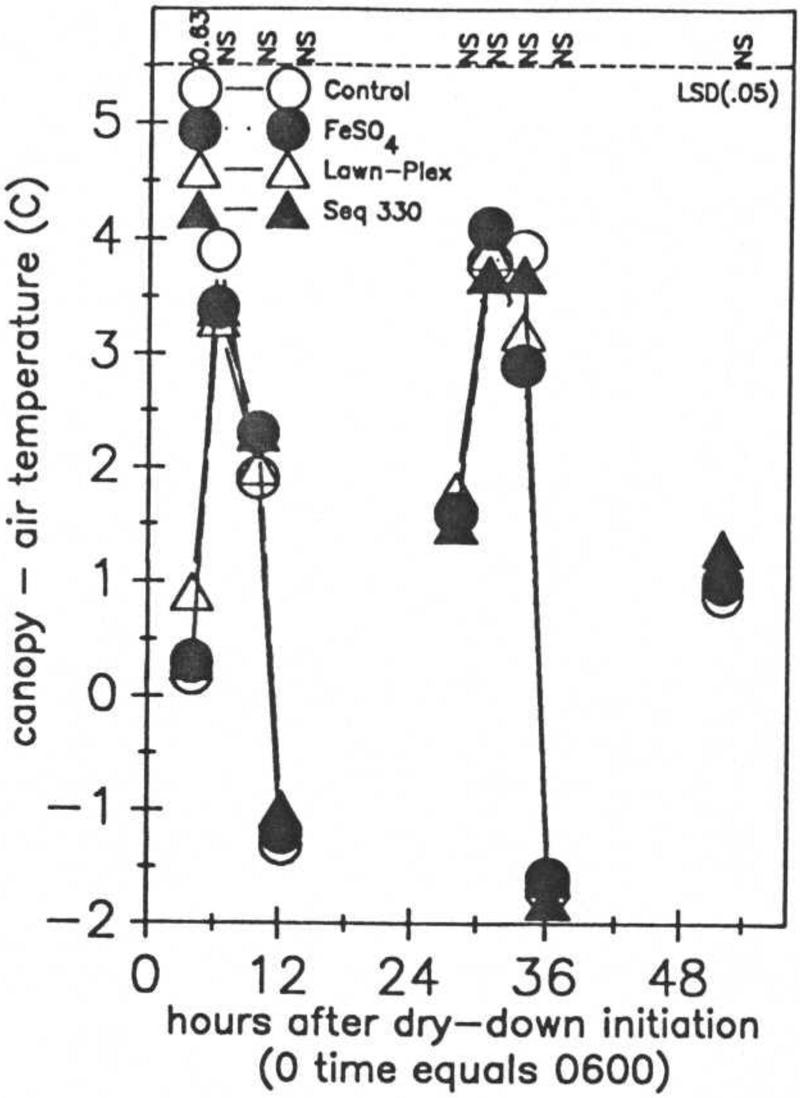
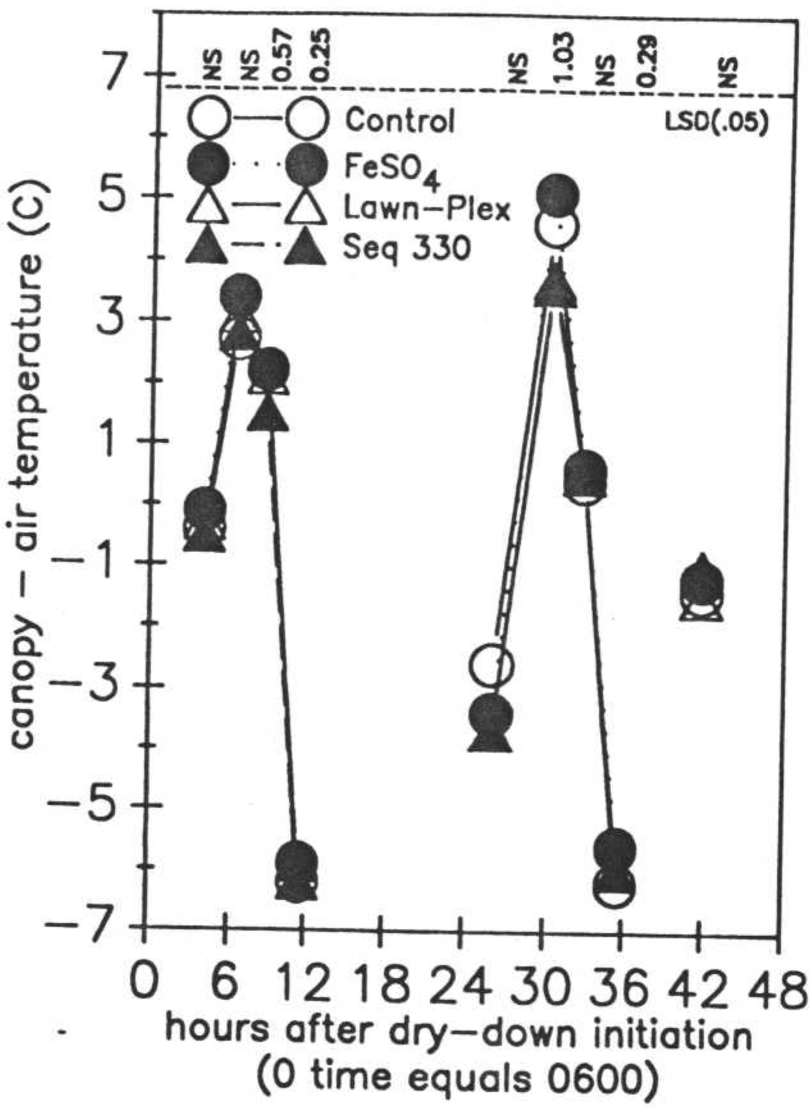

0.63
NS
NS
NS
NS
NS
NS
NS
NS
Control
FeSO4
Lawn-Plex
Seq 330
LSD(.05)
5
4
3
2
1
0
−1
−2
canopy − air temperature (C)
0
12
24
36
48
hours after dry−down initiation
(0 time equals 0600)

Figure 8. Canopy temperature minus air temperature on a bentgrass green, October 1988: Average temperature difference of well watered (100%) and water stressed (80%) treatments as influenced by various Fe fertilizers.



NS
NS
0.57
0.25
NS
1.03
NS
0.29
NS
LSD(.05)
Control
FeSO4
Lawn-Plex
Seq 330
canopy – air temperature (C)
7
5
3
1
–1
–3
–5
–7
0
6
12
18
24
30
36
42
48
hours after dry-down initiation
(0 time equals 0600)