IRON FERTILIZATION ON CREEPING BENTGRASS. I. EFFECTS ON SHOOT QUALITY AND GROWTH[1]

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ABSTRACT

Drought and heat stress frequently diminish the physiological health and appearance of creeping bentgrass (Agrostis palustris Huds.) golf greens in the Southeastern United States. This study was initiated to determine the effect of Fe on Fe-sufficient bentgrass color and shoot growth, and combine these findings with a companion study to evaluate the ability of Fe to enhance bentgrass drought tolerance and rooting. Ferrous sulfate ($FeSO_4 \cdot 7H_2O$), Lawn-Plex (Fe phosphate-citrate), and Sequestrene 330 (sodium ferric diethylenetriaminepentacetate) were applied to an experimental bentgrass golf green at 1.12 kg $Fe \cdot ha^{-1}$ per month over a 17 month period. Responses of visual quality, color, and shoot growth were monitored 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) and compared to untreated plots. Iron improved color throughout the year, but least in the summer. Iron improved summer color 5.9% compared to 8.6 to 9.5% for all other seasons. Visual quality improved in response to Fe in all seasons except summer. Color and visual quality responses were similar for all Fe sources. Total extractable tissue Fe had a low correlation with color ($<r=0.54$). Iron carriers had different effects on growth, especially between late-summer

and winter. Lawn-Plex promoted cool season clipping yields while Seq 330 reduced verdure in the summer by 18% compared to the control. These results show iron's influence on bentgrass is primarily a color response. Shoot growth responses may occur but depend on the Fe carrier rather than elemental Fe.

Creeping bentgrass (Agrostis palustris Huds.) provides an excellent surface for golf greens. Although the cool-season species adapts best to temperate climates, it is widely used in mid to northern areas of the Southeast. Superintendents in these hot, humid climates often encounter difficulty in maintaining acceptable stands of bentgrass. Close mowing and frequent use subject the bentgrass greens to severe summer stress.

Iron has been applied to promote a darker green color for turfgrass 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; Yust et al., 1984). In Virginia, Snyder and Schmidt (1974) reported the greatest Fe color enhancement during cool, dry periods. However, the magnitude of color improvement that may occur under Southeastern climatic conditions, where Fe deficiency is not common, has not been reported.

Shoot growth responses to Fe applications under Fe-sufficient conditions remain unclear. Snyder and Schmidt (1974) and Schmidt and Snyder (1984) indicate Fe fertilizers increase spring growth and decrease summer (June) growth of bentgrass. In contrast, Carrow et al. (1988) found centpedegrass [Eremochloa ophiuroides (Munro.) Hack.] summer growth uneffected by Fe applications, as did

Yust et al. (1984) on Kentucky bluegrass (Poa pratensis L.) during July and Aug. in Illinois.

The influences of Fe on shoot color and growth, combined with its possible promoting effect on root growth (Horst, 1984; Deal and Engel, 1965; Schmidt and Snyder, 1984; Snyder and Schmidt, 1974), may alone, or in combination with other physiological changes, enhance bentgrass drought tolerance. Snyder and Schmidt (1974) found Fe applications reduced the tendency of bentgrass winter desiccation, while Schmidt (1986) maintained Fe applications to turf grown on non-calcareous soils improved desiccation tolerance of newly sodded grass .

Shoot growth reponses to Fe could influence drought tolerance by altering transpiration. Sharma and Sharma (1987) found low Fe reduced transpiration of cauliflower (Brassica oleracea L. botrytis) and attributed this response to larger stomatal opening and lower diffusive resistence. Low Fe also reduced leaf thickness and enhanced wilt. Indirectly, Fe could reduce transpiration through its ability to improve turfgrass color. Most turfgrass managers use N to improve color. The fast, succulent growth often associated with N promotes transpirational water loss (Shearman, 1985). Thus, if Fe reduces the necessity of applying N for acceptable color, growth and water loss could be reduced. Iron's effect on color could also potentially improve drought resistence through effects on photosynthsesis and carbohydrate production causing increased root growth. Iron could increase root growth by increasing root carbohydrate utilization by decreasing the percentage of carbohydrates used by shoots (decrease shoot growth), or increasing the photosynthesis and carbohydrate production, as found by Schmidt and Snyder (1984). Overall, the increased root growth might provide better water extracting potential for enhanced drought tolerance.

The purpose of this research was to investigate the effects of foliar applied Fe on shoot quality and growth of a Fe-sufficient bentgrass golf greens grown in the Southeast. In addition, this data provides preliminary information on the ability of Fe to influence drought tolerance by affecting shoot growth. Iron response during the summer months received special attention. A companion paper (Glinski et al., 1989a) investigates the ability of Fe to influence drought tolerance by evaluating summer-Fe effects on root growth, water use, canopy temperature, and resistence to wilt.

MATERIALS AND METHODS

The research was conducted on a one-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 x 4.6 m each).

Mowing was every 2 or 3 days with a reel mower at a height of 0.4 cm with clippings collected. Fertilizer applications were on an 'as needed' basis: urea (45-0-0) at 48.8 kg $N \cdot ha^{-1}$ (Mar., Oct. 1987; Feb., Mar. 1988), urea at 36.6 kg $N \cdot ha^{-1}$ (May., Aug. 1987; May 1988), urea at 24.4 kg $N \cdot ha^{-1}$ (Apr., May, July, Sept.; Nov. 1987); NH_4NO_3 (33-0-0) at 48.8 kg $N \cdot ha^{-1}$ (Feb. 1987); isobutylidenediurea (IBDU, 33-0-0) at 48.8 kg $N \cdot ha^{-1}$ (Dec. 1987); Scotts[1] (22-0-16) at 48.8 kg $N \cdot ha^{-1}$ (June 1988); 10-10-10 at 48.8 kg $N \cdot ha^{-1}$ (Jan. 1988). In addition to the P and K added with N (Dec. 1987 and June 1988), plots received 21 kg $P \cdot ha^{-1}$ and 81 kg $K \cdot ha^{-1}$ in May and Oct. 1988 as triple superphosphate and KCl, respectively. Soil pH was 5.75. Bensulide plus oxidiazon (Scotts[1]) was applied in Mar. 1987 and 1988 at 5.4+1.35 kg

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

$ai \cdot ha^{-1}$ for preemergence annual grass control. Preventative fungicide and insecticide programs were used throughout the study with Fe-free materials.

Experimental design consisted of a 4 x 2 factorial (4 Fe carriers x 2 irrigation levels) in a completely randomized block design with three replications. Iron treatments included a control and three different Fe carriers: (a) iron sulfate (FS)--Fisher Analytical Reagent $FeSO_4 \cdot 7H_2O$ (Fair Lawn, NJ), 20% Fe, 12% S; (b) Lawn-Plex (LP)--R.G.B Laboratories Fe phosphate-citrate (Kansas City, MO), 8% Fe, 8% S; and (c) Sequestrene 330 (Seq 330)--Ciba-Geigy sodium ferric diethylenetriaminepentacetate (Greensboro, NC), 19% 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 in the presence of dew. Each plot replication 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. Also, during the study plots were subjected to four, three-day, drought-stress periods: July, Aug., Sept. 1987, and June 1988. These stress periods provided data on the interaction between Fe applications and bentgrass water-stress responses which are reported in a companion paper (Glinski et al., 1989a).

To evaluate the influence of Fe carriers on turfgrass visual quality and color, plots received monthly ratings. In the summer (July, Aug, and Sept 1987) weekly ratings occurred. Quality ratings ranged from 9 to 1 (9=ideal shoot density, uniformity, texture, and color; 1=no live turf). Color ratings ranged from 9 to 1 (9=dark green, 1=no green, all brown or yellow). Ratings were analyzed by individual dates and in groups (seasons). Due to the large number of individual readings, only seasonal results appear within this paper. In addition to the visual color ratings, summer color was evaluated with the aid of Munsells Color Chart for Plant Tissue (Munsell Color, Baltimore Maryland).

Clippings were collected at least once a month. During the summer, clipping collection occured 1 to 2 days before, and 7 to 10 days after Fe applications. Using the two front reels of a tri-plex reel mower, a single pass (3.65 m long) through the center of a plot encompassed 3.72 m^2. During the summer months, immediately after collecting clippings, samples were washed in a 1% soap solution (Liqui-Nox, Alconox, New York, N.Y.), rinsed in distilled water and dried (80°C for 24 h) for later weight and Fe analysis. No prewashing occurred during the other months. All samples were ground in a stainless steel Wiley mill (40 mesh screen). Iron content was determined after wet digestion by atomic absorbtion spectrophotometry (Isaac and Kerber, 1977).

Verdure samples were collected twice during the summer (18 July and 21 Aug). Three cores (5.7 cm dia x 3.0 cm deep) were removed from a triangular grid placed in a plot quadrant. Live tissue was cut at the soil line and dried (1 h at 100°C, and 24 h at 70°C). Verdure content was evaluated on a weight basis.

Data was analyzed using Statistical Analysis Systems procedures for correlation and GLM (SAS Institue, 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

Snyder and Schmidt (1974) and Schmidt (1986) reported a favorable effects of Fe on turfgrass color, density, root development, and resistence to winter desiccation. They also noted larger responses during stressful years. In a follow-up study, however, under greenhouse conditions, Schmidt and Snyder (1984) reported no interaction between Fe and irrigation level. This study contained well watered and moderate water-stressed conditions which further evaluated the effects of Fe fertilizers under different irrigations regimes. Few irrigation treatment and no Fe carrier x irrigation responses occurred on shoot growth. However, interactions occurred with water use and other data reported in a companion paper (Glinski et al., 1989a). In order to maintain consistency, and illustrate trends, both irrigation levels were reported in this paper.

Color. Iron carrier treatments enhanced turfgrass color in all seasons (Table 1). Little difference occurred between Fe carriers besides FS producing significantly darker color than either Seq 330 or LP on two days (individual days not reported). In these cases, the magnitude of color improvement from FS versus LP and Seq 330 were slight. Close observation of the individual ratings (not given) suggests Fe improves color least in the summer. From 6 July to 7 Sept. 1987, 30% of the individual ratings (not presented) showed no Fe carrier effect (30, 26 and 25 days after Fe application), while 40% of the effects were significant, but between 1 and 10%. In contrast, ratings from other seasons (15) showed significant Fe effects with all but three significant at less than the 1% level (April and May 1987, and April 1988). When significant color response to Fe carrier occurred, the magnitude of response from Fe application tended to be greater in the cooler seasons relative to the mid summer months. When averaged over all Fe carriers and compared to the control, color improved from Fe applications by 8.6, 8.6, 9.6, and 5.9%, repectively, for the spring, early summer, fall/winter, and mid to late summer.

These findings agree with reports of Fe fertilization improving turfgrass color under Fe-sufficient situations (Carrow et al., 1988; Christians, 1984; Schmidt and Snyder, 1984; and Snyder and Schmidt, 1974; Yust et al., 1984;). However, seasonal effects remain obscure. Spring-early summer conditions reportedly hinder color improvement (Snyder and Schmidt, 1974; Schmidt and Snyder, 1984; Yust et al., 1984). In Illinois, Yust et al. (1984) found Fe applications improved Kentucky bluegrass color with the duration of improvement being least in cool, wet springs (6-21° C, average 5.8 mm precipitation per day), and greatest in cool, dry falls (2-21° C, average 2.0 mm precipiation per day), but the magnitude of improvement appeared equivalent. Glinski et al. (1989b) found late spring greenhouse conditions (23.9± 5° C, 13 mm of irrigation per day) had little effect on bentgrass color. Snyder and Schmidt (1974) noted applications of Fe, in the presence of low temperatures, had slight, short lasting (less than 7 days) effect on color under a low N regime (one application at 50 kg N·ha^{-1}). Under a moderate to high N regime (monthly applications at 50 kg N·ha^{-1}), fall-winter Fe applications improved winter-spring color. Similarly, Schmidt and Snyder (1984) reported applications of FeDTPA under simulated fall/winter/spring conditions improved spring color on all dates measured. The magnitude of improvement increased as temperature increased. Christians (1984), found June Fe+N treatments (2.4-7.3 kg Fe·ha^{-1} and 24-49 kg N·ha^{-1}) enhanced Kentucky bluegrass for six days, while Sept. treatments had no color effect. We found color improvement in spring less significant than in fall and winter, but summer Fe applications had the least impact on turfgrass color. Weather conditions during the study were warmer and drier than normal.

Most of the color differences observed in this study reflect differences in magnitude. Other authors report differences in duration of color response. Snyder and Schmidt (1974) and Yust et al. (1984) found Fe enhanced spring color for approximately 2 weeks, and enhanced fall/winter color for several months. In this study, monthly Fe applications eliminated the evaluation of longterm color effects. However, short-term (less than a month) color effects could be observed. During the spring, color improvement persisted for at least 28, 21 and 37 days after Fe application (April and May 1987 and April 1988--data not presented for these dates). Color effect did not necessarily decrease after these times, instead, Fe applications occurred before another color rating. During the summer, the duration of color improvement were shortest. Three rating dates (6 July, 10 Aug., and 7 Sept.) showed no Fe effect. These ratings occurred 30, 26, and 25 days after Fe application.

Schmidt (1986) suggests spring soil temperatures optimize microbial activity and plant metabolism which stimulate Fe availability; thus, with Fe readily available, spring Fe applications have little effect. In addition, fast spring shoot growth may decrease chlorophyll concentration and therefore observed differences between Fe and control treatments. Fast leaf growth associated with spring temperatures (ambient 21-27° C), could also promote tissue removal from mowing and thus a shorter duration of color improvement. Several factors may cause poor summer response. Thick cuticles may hinder Fe absorbtion during the hot summer months. Reduced root growth may decrease soil absorbtion. Also, recent research shows ultra-violet (UV) radiation decreases foliar Fe absorption and activity (Jolley et al., 1987; Pushnik et al., 1987). High summer UV may decrease the effect of Fe. The apparent discord between seasonal color results may reflect the lack of data on the effects of summer Fe applications on bentgrass. As stated earlier, year-round effects of Fe applications on bentgrass have not previously been reported. In addition, differences arise from Fe rate, grass species, location of study, and native soil Fe. Also, an environmental variable probably contributes to a lack of correlation between results. More effort is probably required in reporting air and soil temperature as well as precipitation.

Tissue Fe Content. Generally, Fe carriers did not significantly increase tissue Fe content of samples collected 7 to 31 days after Fe application (Table 2). Consistent trends, however, appeared. Lawn-Plex and FS treated turfgrass exhibited higher Fe contents than the control, and, to a lesser extent, Seq 330. Lawn-Plex maintained a higher average leaf-Fe content than the control on all dates. Ferrous sulfate had a higher content 82% of the time. Seq 330 had an average content higher than the control 54% of the time. The presence of sulfur (S) in LP and FS, but not Seq 330 may relate to the lower Fe contents of Seq 330 treatments--S possibly decreasing soil pH and therefore increasing Fe availability absorption. Ferrandon et al. (1988) found greater foliar uptake of inorganic over chelated Fe, while chelated Fe displayed greater translocation. This may help explain why Seq 330 treatments could maintain lower tissue Fe content, but manifest similar color as FS.

The high variability in leaf-Fe contents demonstrate the difficulty in obtaining contaminant-free samples, as reported by Smith and Storey (1976). They showed a wash sequence of soap, dilute HCl and distilled water aided in the removal of contaminant Fe. In our study, tissue Fe content appeared low from June through Sept. 1987. These low readings coincide with the use of a pre-wash in a 1% soap solution. These readings (soap-washed) were lower and had less variability than unwashed readings. Most statistical differences occurred within the soap-washed time frame. Apparently, external Fe content may cause large variation and contribute to the lack of statistical difference.

Tissue Fe content did not correlate well with color. The highest correlations occured 17 Sept (r=0.54) and 13 Nov (r=0.49) of 1987. Besides the problem of obtaining clean samples, determining and extracting the "active" form of Fe may contribute to the lack of correlation. The wet digestion removes all plant Fe, but evidence indicates quantification of chloroplast lamellae bound Fe correlates best to chlorophyll content (Terry and Low, 1982).

Iron content versus chlorophyll content and color relationships remain enigmatic, especially under Fe-sufficient situations. Oertli (1963) and Harivandi (1986) report specific Fe levels that indicate Fe chlorosis in turfgrasses. Other researchers (Bennet, 1945; Mengel, 1982; Hamze and Nimah, 1982; and Wallace et al., 1982) have found healthy tissue may contain less Fe than Fe-chlorotic tissue. Harivandi and Butler (1980), Madison and Anderson (1963), Minner and Butler (1984), Pocklington et al. (1974) and Yust et al. (1984) reported positive correlations between tissue Fe content and/or chlorophyll content. Yet, Minner and Butler (1984), Seitz and Kneebone (1970), Carrow et al. (1988), and Pierson et al. (1986) have found no correlation between Fe content and chlorophyll and/or color. Undoubtedly, some of the discrepancy reflects differing pre-wash procedures, use of different grass species, the presence or absence of chlorotic conditions, and measuring active or total Fe.

Duble (1986) reported leaf Fe contents of 0-50 (deficient) and 51-200 mg $Fe \cdot hg^{-1}$ (low). Summer month values of leaf Fe in the control treatment often were within the low range. Iron applications raised tissue Fe contents into the moderate range (201-1000 mg $Fe \cdot hg^{-1}$).

Visual Quality. Results show Fe fertilizers improved turfgrass visual quality in all seasons except early summer through early fall of 1987 (Table 3). All sources had similar effects, except the spring-summer visual quality response of FS persisted later into the summer than other treatments, and a positive early fall response of Seq 330 was observed. The significant early summer effect in 1988 for all Fe sources, and not 1987, may reflect climatic variation. Also, in 1988 visual quality was based on a single rating. In 1987, several ratings were averaged over a longer time period and into mid-July.

Turfgrass researchers evaluate visual quality as an integrated value of shoot density, color, uniformity, and texture. In a greenhouse study, Glinski et al. (1989b) found Seq 330 had a tendency to improve bentgrass quality (FS and LP had no effect). Schmidt (1986) reported applications of FeDTPA increased Kentucky bluegrass shoot density, a component of visual quality. Deal and Engel (1965) reported increased density of Kentucky bluegrass associated with Fe applications. Carrow et al. (1988) found Fe sources (FS, ferrous ammonium sulfate and Seq 330) equally enhanced visual quality of centipedegrass and Fe source had no effect on magnitude or duration of response. In this study, improved visual quality reflected improved color, which contributes to visual quality, rather than higher shoot density.

Clipping Yields. Iron treatment main effect analysis showed that Fe influenced clipping yields on some dates (Table 4). However, Fe carriers differed in their influence on clipping yields. Lawn-Plex produced significantly higher yields than the control in Sept. and Oct., while FS and LP did not increase yields. In fact, Seq 330 appeared to produce less growth than the other treatments, especially LP. These differences may relate to the presence of sulfur in FS and LP, but not Seq 330. Most significant yield differences among Fe carriers occurred in the fall period.

Previous research results conflict as to whether Fe influences turfgrass shoot growth. Horst (1984) reported Fe increased top growth during bermudagrass establishment. Carrow et al. (1988) (centipedegrass), Deal and Engel (1965) and Yust et al. (1984) (Kentucky bluegrass) found Fe had no effect on top growth. Yet, Deal and Engel (1965) reported increased density under high fertility. On bentgrass greens, Snyder and Schmidt (1974) reported monthly fall-winter Fe applications (FeDTPA) tended to increase spring shoot growth, while spring application (under a high N regime), decreased June shoot growth. In a follow-up investigation, Schmidt and Snyder (1984) found similar results with Seq 330: FeDTPA increased growth during cool ambient conditions (growth chamber) and decreased growth as temperature increased. Glinski et al. (1989b) found Fe sources had little effect on turfgrass growth under simulated springlike greenhouse conditions.

Verdure. Verdure measurements indicate Seq 330 reduced turfgrass growth (Table 5). Relative to the control, Seq 330 decreased verdure by about 18% in July and Aug. Comparing this data with clipping data of others (Carrow, 1983; Schmidt and Snyder, 1984), it appears that, although not always significant, Seq 330 tends to reduce turfgrass growth. Since other Fe treatments did not decrease growth, the carrier probably contributed to the effect. Schmidt and Snyder (1984) suggested FeDTPA's influence on shoot growth depended on temperature and growth rate; during warm temperatures and fast growth, succulent leaf tissue absorbs more FeDTPA. The FeDTPA then acts as a minor growth regulator (Burstrom, 1963; Wallace et al., 1957). Our results indicate the most significant growth effects of FeDTPA (seq 330) tend to occur in late summer through early winter (Aug-Nov 1987), rather than spring. Variation in results probably reflects differences in experimental design. We concentrated on summer effects, neglecting some winter-spring clipping collections. Schmidt and Snyder (1984) concentrated on fall/winter/spring effects, disregarding summer clipping collections and summer Fe applications.

The variance in influence of Fe carrier on clipping yield and verdure ranged from no apparent effect for FS, a tendency for somewhat greater clipping yields for LP, to a tendency for reduced clipping yield and verdure for Seq 330. This implies that care must be exercised in attributing a particular response to Fe, especially when using a single carrier. Other components in the carrier may cause certain plant responses rather than Fe.

Another implication of the shoot growth data on Seq 330 is that reduced verdure and/or clipping production could increase the potential for wear injury and reduced recovery rate. Increased verdure provides a cushioning effect to reduce wear, while adequate clipping production furnishes the primary means of recovery from wear.

While Fe application on creeping bentgrass in the stressful summer months is a common grower practice, these research results indicate shoot responses are minimal. Some color improvement may occur in the summer but of such a small magnitude as to have little influence on overall visual quality. Verdure was reduced to some extent by Seq 330, but this appears to be a carrier rather than true Fe response. Clipping yield responses occurred but primarliy in the fall and were not of great magnitude. However, the fact that summer leaf Fe contents were often low for bentgrass not receiving Fe suggests a possible benefit from summer Fe applications. Detailed physiological studies would be necessary to define any effects on plant physiological processes.

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Table 1. Color response during different seasons of a bentgrass golf green to monthly applications (Apr. 1987 to June 1988) of various Fe fertilizers.

Treatment		Color							
		1987					1988		
FeC[a]	Irr[b]	Spring 2 April-29 May	Early Summer 6 June-13 July	Late Summer 20 July-31 Aug	Early Fall 7 Sept-20 Sept	Late Fall 17 Oct-28 Dec	Winter 15 Jan-11 Mar	Spring 29 Apr-17 May	Early Summer 16 June
		9=dark green, 1=no green							
None	100%	7.2	6.9	6.8	7.2	7.0	6.4	6.6	7.1
None	80	7.1	6.9	6.7	6.7	6.5	6.5	6.8	7.1
Avg		7.2	6.9	6.7	6.9	6.7	6.4	6.7	7.1
$FeSO_4$	100	7.8	7.4	7.2	7.8	7.5	7.3	7.5	7.8
$FeSO_4$	80	7.9	7.3	7.2	7.5	7.4	7.5	7.6	8.1
Avg		7.8	7.4	7.2	7.7	7.5	7.2	7.5	7.9
Lawn-Plex	100	7.6	7.4	7.1	7.6	7.3	7.3	7.4	7.5
Lawn-Plex	80	7.5	7.4	7.1	7.5	7.5	7.2	7.4	7.9
Avg		7.6	7.4	7.1	7.5	7.4	7.2	7.4	7.7
Seq 330	100	7.6	7.3	7.1	7.9	7.4	7.3	7.3	7.7
Seq 330	80	7.6	7.3	6.9	7.6	7.3	7.5	7.4	8.1
Avg		7.6	7.3	7.0	6.8	7.4	7.4	7.4	7.9
Irrigation Avg									
	100	7.6	7.3	7.0	7.6	7.3	7.1	7.2	7.5
	80	7.5	7.2	7.0	7.3	7.2	7.2	7.3	7.8
CV(%)		2.4	2.1	2.5	3.0	3.5	3.0	3.1	4.3
Statistical Significance									
FeC		.001[c]	.001	.002	.001	.001	.002	.001	.001
Irr		NS	NS	NS	.001	NS	.066	NS	NS
FeC x Irr		NS	NS	NS	NS	NS	NS	NS	NS
Contrasts[d]									
None x $FeSO_4$		.001	.001	.001	.001	.001	.001	.001	.001
None x Lawn-Plex		.004	.001	.001	.001	.001	.011	.001	.001
None x Seq 330		.003	.002	.024	.001	.001	.001	.001	.001

a Fe applied monthly, 1.12 kg Fe ha^{-1}.
b 100% irrigation (Irr)=0.99 cm water every 2 days.
c NS=not significant using F-Test at 10%; 'number'=significant level using F-Test at 10%.
d Contrasts on average of irrigations regimes.

Table 2. Leaf Fe content during different seasons of a bentgrass golf green receiving monthly applications (Apr. 1987 to June 1988) of various Fe fertilizers.

Treatment		Date										
FeC[a]	Irr[b]	18 May 31[c]	19 June 29	29 June 7	14 July 22	23 July 8	11 Aug 27	25 Aug 12	9 Sept 27	17 Sept 7	17 Oct 2	13 Oct 29
						$mg\,kg^{-1}$						
None	100%	673	190	171	118	224	155	157	230	116	317	757
None	80	552	173	197	141	191	151	174	166	113	363	781
Avg		613	182	184	130	208	153	165	198	114	340	769
$FeSO_4$	100	836	582	569	146	325	147	301	315	226	403	837
$FeSO_4$	80	651	331	387	146	303	155	284	255	240	418	669
Avg		743	457	478	146	314	151	292	285	233	410	753
Lawn-Plex	100	660	208	307	145	356	182	473	429	241	446	805
Lawn-Plex	80	1930	250	395	151	279	186	266	187	251	386	1352
Avg		1295	229	351	148	317	184	369	308	246	416	1079
Seq 330	100	687	153	181	135	290	140	211	162	184	319	696
Seq 330	80	726	206	229	129	231	143	260	164	178	332	711
Avg		706	179	205	132	261	141	335	163	181	325	704
Irrigation Avg												
	100	714	283	307	136	299	156	285	284	192	371	774
	80	965	240	302	142	251	158	246	193	196	375	878
CV(%)		85	100	72	21	27	19	52	71	15	22	48
Statistical Significance												
FeC		NS[d]	NS	NS	NS	.079	NS	NS	NS	.001	NS	NS
Irr		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
Contrasts[e]												
None x $FeSO_4$		NS	.091	.036	NS	.029	NS	NS	NS	.001	NS	NS
None x Lawn-Plex		NS	NS	NS	NS	.025	NS	.023	NS	.001	NS	NS
None x Seq 330		NS	NS	NS	NS	NS	NS	NS	NS	.001	NS	NS

a Fe carrier, Fe applied monthly, 1.12 kg Fe ha^{-1}.
b 100% irrigation (Irr)=0.99 cm water every 2 days.
c Days after last Fe application.
d NS=no significance using F-test at 10% level; 'number'=significant using F-test at 10%.
e Contrasts of irrigation averages within a treatment.

Table 3. Visual quality response during different seasons of a bentgrass golf green to monthly applications (Apr. 1987 to June 1988) of various Fe fertilizers.

Treatment		Visual Quality							
		1987					1988		
FeC[a]	Irr[b]	Spring 2 April- 29 May	Early Summer 6 June- 13 July	Late Summer 20 July- 31 Aug	Early Fall 7 Sept- 20 Sept	Late Fall 17 Oct- 28 Dec	Winter 15 Jan- 11 Mar	Spring 29 Apr- 17 May	Early Summer 16 June
		9=ideal, 1=no live turf							
None	100%	6.5	6.5	6.6	6.5	6.4	6.4	6.5	6.4
None	80	6.4	6.5	6.5	6.4	6.4	6.4	6.4	6.6
Avg		6.4	6.5	6.6	6.5	6.4	6.4	6.4	6.5
$FeSO_4$	100	7.0	6.9	6.8	6.5	6.8	7.2	7.2	7.4
$FeSO_4$	80	7.0	6.8	6.5	6.5	6.8	7.2	7.1	7.2
Avg		7.0	6.8	6.7	6.5	6.8	7.2	7.1	7.3
Lawn-Plex	100	6.9	6.7	6.6	6.4	6.7	7.2	7.1	6.9
Lawn-Plex	80	7.0	6.8	6.7	6.5	6.7	7.3	6.9	7.3
Avg		6.9	6.8	6.7	6.5	6.7	7.3	7.0	7.1
Seq 330	100	7.0	6.7	6.7	6.7	6.8	7.1	7.1	7.4
Seq 330	80	7.0	6.7	6.7	6.8	6.9	7.2	7.2	7.4
Avg		7.0	7.0	6.7	6.8	6.8	7.1	7.1	7.4
Irrigation Avg									
	100	6.8	6.7	6.7	6.5	6.7	7.0	6.9	7.0
	80	6.8	6.7	6.6	6.5	6.7	7.1	6.9	7.1
CV(%)		4.2	5.1	3.8	4.3	3.1	2.2	4.3	3.8
Statistical Significance									
FeC		.009[c]	NS	NS	NS	.018	.001	.002	.001
Irr		NS	NS	NS	NS	NS	NS	NS	NS
FeC x Irr		NS	NS	NS	NS	NS	NS	NS	NS
Contrasts[d]									
None x $FeSO_4$		.002	.079	NS	NS	.008	.001	.001	.001
None x Lawn-Plex		.007	NS	NS	NS	.046	.001	.003	.002
None x Seq 330		.006	NS	NS	.053	.004	.001	.001	.001

a Fe carrier, Fe applied monthly, 1.12 kg Fe ha^{-1}.
b 100% irrigation (Irr)=0.99 cm water every 2 days.
c NS=not significant using F-Test at 10%; 'number'=significant level using F-Test at 10%.
d Contrasts on average of irrigation levels.

Table 4. Clipping yield response during different seasons of a bentgrass golf green to monthly applications (Apr. 1987 to June 1988) of various Fe fertilizers.

Treatment		Date										
Fe Carrier[a]	Irrigation[b]	5-18 31[c]	6-19 27	6-29 7	7-14 22	7-23 8	8-11 27	8-25 12	9-9 27	9-17 7	10-17 2	11-13 29
							$g\,m^{-2}$					
None	100%	5.57	4.74	5.11	2.41	4.62	6.71	3.32	3.54	2.03	5.47	7.35
None	80	5.45	3.68	5.35	2.39	4.66	5.89	3.16	3.14	1.77	5.77	9.15
Avg		5.28	4.21	5.23	2.40	4.64	6.30	3.24	3.34	1.90	5.62	8.25
$FeSO_4$	100	5.27	4.57	4.54	2.82	4.86	6.84	3.20	3.30	2.39	6.33	9.78
$FeSO_4$	80	5.46	4.67	5.82	2.56	4.28	5.70	3.46	2.71	1.63	6.19	4.84
Avg		5.36	4.62	5.18	2.69	4.57	6.27	3.33	3.00	2.01	6.26	7.31
Lawn-Plex	100	5.81	4.01	6.10	2.66	4.61	6.29	3.83	3.51	3.00	7.40	9.69
Lawn-Plex	80	5.29	5.25	6.09	2.66	4.89	6.24	3.45	3.61	2.36	6.32	12.56
Avg		5.55	4.63	6.09	2.66	4.75	6.26	3.64	3.66	2.68	6.86	11.12
Seq 330	100	4.95	3.71	4.31	2.02	4.38	6.60	2.82	3.57	2.43	6.11	7.62
Seq 330	80	4.54	4.02	4.77	2.36	4.43	5.81	2.78	3.17	2.13	5.62	6.55
Avg		4.74	3.86	4.54	2.19	4.40	6.20	2.80	3.37	2.28	5.86	7.08
Irrigation Avg												
	100	5.40	4.26	5.01	2.48	4.62	6.61	3.29	3.48	2.46	6.33	8.61
	80	5.18	4.40	5.51	3.23	4.56	5.91	3.21	3.16	1.97	5.97	8.27
CV(%)		16.8	20.5	18.0	27.8	16.6	19.2	15.9	17.8	24.4	13.0	42.6
Statistical Significance												
FeC		NS[e]	NS	.083	NS	NS	NS	.084	NS	NS	.081	NS
Irr		NS	NS	NS	NS	NS	NS	NS	NS	.044	NS	NS
FeC x Irr		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Contrasts[d]												
None x $FeSO_4$		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
None x Lawn-Plex		NS	NS	NS	NS	NS	NS	NS	NS	.025	.017	NS
None x Seq 330		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

a Fe carrier, Fe applied monthly, 1.12 kg Fe ha^{-1}.
b 100% irrigation (Irr)=0.99 cm water every 2 days.
c Days after last Fe application.
d NS=not significant using F-Test at 10%; 'number'=significant level using F-Test at 10%.
e Contrasts on average of irrigation regimes.

Table 5. Verdure content of a bentgrass golf green as influenced by monthly applications (Apr. 1987 to June 1988) of various Fe fertilizers.

Treatment		Verdure, $g \cdot m^2$	
Fe[a]	Irrigation[b]	24 July	19 August
None	100%	539	573
None	80	633	513
Avg		568	543
$FeSO_4$	100	451	473
$FeSO_4$	80	609	441
Avg		530	457
Lawn-Plex	100	620	556
Lawn-Plex	80	571	410
Avg		596	483
Seq 330	100	474	426
Seq 330	80	461	456
Avg		468	440
Irrigation Avg			
	100	521	507
	80	569	455
CV(%)		20.5	19.6
Statistical Significance			
FeC (Fe carrier)		NS[c]	NS
Irrigation (Irr)		NS	NS
FeC x Irr		NS	NS
Contrasts[d]			
None x $FeSO_4$		NS	NS
None x Lawn-Plex		NS	NS
None x Seq 330		.087	.080

a Fe applied at 1.12 kg $Fe \cdot ha^{-1}$ a month.
b 100% = 0.99 cm water every 2 days.
c NS=not significant using F-Test at 10%;
'number'=significant level using F-Test at 10%.