TURFGRASS GROWTH, WATER USE, AND SOIL AERATION STATUS UNDER IRRIGATION AND SOIL COMPACTION REGIMES

by

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LITERATURE REVIEW

Introduction

Compaction is a continuous problem where traffic occurs on soils. Heavy agricultural equipment has caused severe compaction problems over large acreages, most frequently occurring in the surface 30.5 cm (9, 70). This differs from turfsites where soil compaction is usually confined to the top 2.5 to 7.5 cm with the greatest compaction occurring in the surface 2.5 cm (10, 17, 31, 45, 44, 85).

Compaction influences the physical, chemical, and biological properties of soils (51). The exact effects of compaction on turfgrass growth and management are unclear and experimental evidence is limited (15). An understanding of this problem is necessary in order to more efficiently manage high traffic sites.

In more recent years water has become a serious problem of turfgrass managers as well as American industry (25). Water is becoming a diminishing resource and many of our practices and attitudes must be changed (25, 78). On recreational sites soil compaction interferes with efficient water use. The purpose of this study is to provide more insight into the effects of soil compaction on soil physical properties, turfgrass growth, and efficient water use.

Compaction Effects On Soil Physical Properties

Compaction is the pressing together of soil particles into a more dense mass (10). When compaction occurs, the soil physical properties are altered. No one soil measurement is sufficient in determining the degree of compaction. These soil physical properties are interrelated and the degree to which they change depends on soil type and conditions under which compaction occurs.

Bulk Density

Soil bulk density is a common measurement made by researchers to determine the degree of compaction (7, 12, 15, 16, 18, 23, 27, 43, 44, 54, 59, 60, 79, 80, 81). As a soil becomes more dense the pore size distribution is altered which influences moisture retention, aeration, drainage, and infiltration (31). These factors in turn affect turfgrass growth and irrigation practices. Thus, bulk density is an indirect measurement of many changes of soil physical properties.

The bulk density to which a given soil can be compacted under a specified load varies with soil water content. The maximum compaction occurs at about field capacity (9, 12, 23, 31, 32, 45). At that moisture range, water surrounds the soil particles and acts as a lubricant allowing the particles to move closer together. At saturation all the pores are filled and the soil is incompressable (9, 23) but surface rutting and displacement can occur. As soil becomes drier than field capacity there is an increase in strength and resistance to compactive forces. Soils of frequently irrigated turfgrass are often at or near field capacity, making the potential for compaction very high (31).

For a particular soil a critical density can be determined at which root growth starts to decline. However, the critical density varies with soil type and reports in the literature are variable since research was done on different soils.

Beard (10) states that a bulk density of 1.5 g/cm^3 or higher seriously impairs root growth. Rimmer (59) concluded, after many compaction treatments, that a bulk density range of 1.4 to 1.5 g/cm^3 appeared to be the critical density above which growth was reduced. Wilkinson and Duff (81) reported an increase in root growth of three grass species growing at bulk densities from 1.1 to 1.4 g/cm^3. Yet Carrow (17) found that a bulk density increase from 1.27 to 1.34 g/cm^3 caused a decrease in shoot and root growth of Baron Kentucky bluegrass.

Soil Strength

Soil strength, resistance to penetration, is increased with compaction (19, 33, 43, 55, 64, 72). Lowry et al (43) concluded that roots of cotton would not enter a compacted soil zone due to high soil strength. Taylor and Ratliff (65) noted that elongation of both peanut and cotton roots decreased with increasing soil strength caused by compaction. Saini (60) demonstrated that when using penetrometer readings alone as a measure of soil compaction no significant correlation with yield was apparent.

Soil compaction is frequently measured with a resistance to penetration tool but additional data must be taken to accurately measure soil compaction (9, 19, 70). The dominant factor altering soil strength is soil moisture (70). Baver et al (9) described resistance of a soil to penetration as an integrated index of soil compaction, moisture content, texture, and type of clay mineral. Because of this relationship it is difficult to make conclusions from penetrometer readings obtained from different soils and locations (60).

Aeration

Soil aeration is necessary for plant growth. There is approximately fifty percent pore space in most soils but the pore size distribution varies with soil texture. Both small (capillary) and large (non-capillary) pores are necessary for gas exchange, drainage, and water retention. An ideal soil for turfgrass subjected to intense traffic should have a total pore space of 35 to 40 percent with 14 to 20 percent large pores and 18 to 24 percent small pores (10, 24). The amount of non-capillary pores are important when considering soil aeration because they drain away quickly enabling oxygen to enter the soil by either mass flow or diffusion, with diffusion being the principle process (9, 32). Compaction causes a decrease in total pore space with the greatest reduction in large pores (2, 16, 40, 44, 45, 73). Boufford and Carrow (12) and Carrow (17) found a reduction in aeration porosity of 20 and 24 percent, respectively, at -0.1 bar under turfgrass subjected to compaction.

When soil aeration becomes less than the ten percent of the soil volume, root growth is severly reduced or stops (9, 32). But the rate of oxygen exchange at the root rather than the content of soil air is the decisive factor (32, 73). Turfgrasses differ in their ability to survive under low oxygen diffusion conditions (10). Waddington and Baker (74) observed reduced root growth of Merion Kentucky bluegrass at oxygen diffusion rates (ODR) of 5 to 9 x 10^{-8} g/cm^2/min while Pencross creeping bentgrass grew well at an ODR of below 3 x 10^{-8} g/cm^2/min. Letey et al (39) reported that ODR of 20 x 10^{-8} g/cm^2/min is required for root growth of Newport Kentucky bluegrass. For many plants an ODR of 20 to 30 x 10^{-8} g/cm^2/min is limiting to plant growth (40, 45). Oxygen diffusion rates of zero have been reported at 6.4 cm below a compacted turf (44). The survival differences of grasses at low oxygen conditions may be related to the ability of the plant to diffuse oxygen through the root itself by sufficient root porosity (1, 50, 74).

Oxygen diffuses through water at 1/10,000 the rate it diffuses through air (6). Thus, the amount of oxygen diffusing to the root surface is reduced with increasing water film thickness (50). Compaction increases soil moisture retention which in turn increases water film thickness. This problem is compounded by an increase in temperature. Because compaction increases the density of the soil, thermal conductivity is increased, allowing greater soil temperatures to be reached (10, 82). As soil temperatures increase root respiration will also increase (47) with the root tip having the highest respiration rate (46, 49). Increased temperature decreases the solubility of oxygen in water and increases the viscosity in air (49, 73).

Effects of Compaction on Plant Growth

The effects of soil compaction on turfgrass growth are always indirect (70). The responses of turfgrass growth are likely to be an interaction of the altered soil physical properties; increased bulk density, increased soil strength, reduced oxygen, and altered soil water status. A single direct cause of altered plant responses to compaction is difficult to determine.

Rooting

Altered soil physical properties caused by compaction influence root growth. Several investigators have reported reduced root growth due to compaction (12, 17, 37, 43, 54, 56, 59, 72). Cordukes (20) reported a restriction of root growth by one third for a mixture of turfgrasses in a compacted clay soil. Gupta and Abrol (27) compacted a sandy loam soil from 1.38 to 1.70 g/cm^3 and found a progressive decrease in dry weight of roots with the greatest decrease occurring when the bulk density increased from 1.57 to 1.70 g/cm^3. As compaction pressure increased, Thurman and Pokorny (68) observed that root length and dry weight of 'Tifgreen' bermudagrass decreased.

Morphological changes in the root system have also been reported. Baligar et al (7) noted several anatomical differences in soybean roots grown under densities ranging from 1.65 to 1.95 g/cm^3. Roots grown under low densities had a smooth surface of small, unruptured epidermal cells. The cortex was wide with compactly arranged, angular shaped parenchyma cells and a few intercellular spaces. The roots grown under high densities had a wavy surface with large, mostly ruptured, epidermal cells. The perenchyma cells of the cortex were more spherical and there were increased intercellular spaces. Schuurmam and DeBoer (61) found a decrease in root branching when roots entered a dense compacted soil. Nelson et al (55) observed similar findings.

Low oxygen levels have also been shown to change the root system. Aceves-N et al (1) demonstrated low oxygen levels produced shorter, thicker roots with fewer root hairs. The larger root radius may aid the plant in obtaining oxygen by being a larger oxygen sink (50). An increase in root radius can also aid in the percent plant aeration by increasing root porosity (48, 50) which would be important for the survival of a plant under prolonged periods of low soil aeration. Letey et al (37) concluded from morphological changes observed in their compaction study with amended soils, that root morphology of a given plant species is influenced by the medium in which it is growing.

Another response of roots to compaction was observed by Kulkarni and Savant (35). They found that soil compaction increased root-cation exchange capacity and concluded that it was probably due to an increase in the percent nitrogen content of the roots and carboxyl groups on the roots of the crop plants studied.

Shoot Growth

Compaction has been shown to significantly reduce crop yields. Lowry et al (43) observed that compaction at any level other than naturally settled bulk density decreased yield. Phillips and Kirkham (57) attributed mechanical impedance, high bulk densities, and low oxygen levels for reduced yields of corn on a severly compacted Colo clay. Nelson (56) found severe compaction reduced yields 53 percent with low fertility and with fertilizer, yields were reduced by 40 percent. This Iowa study concluded that resistance of soil to roots and decreased ion movement rather than low oxygen levels were responsible for the reduced yields.

Yield is not as important for turfgrass as maintaining a high quality uniform turf, although reduced clipping yields have been reported. Valoras et al (71) found significant reduction in clipping weights of common bermudagrass due to compaction. Thurman and Pokorny (68) observed similar results with 'Tifgreen' bermudagrass, Rimmer (59) also noted reduced shoot growth with increasing compaction although root growth was more affected.

Topgrowth of turf is not only affected by changes in soil physical properties due to compaction but traffic also causes wear. Wear is the physical abrasion and tearing of turfgrass due to concentrated traffic (10). Many studies have been done that combine the effects of both wear and compaction together (13, 15, 16, 20, 26). Very few researches have separated these two aspects of traffic. Shearman and Beard (62) have investigated the effect of wear on several turfgrass species. Boufford and Carrow (12) and Carrow (17, 18) used a smooth power roller to minimize wear and study the effects of compaction only. In all cases compaction significantly reduced visual quality. Carrow (17, 18) also found reduced shoot density, verdure, and percent turf cover. Watson (76) noted an increase in density of bluegrass by compaction and no effect on bentgrass or of red fescue when all three were together as a mix.

One of the many ways compaction reduces shoot growth is by affecting nutrient uptake (56, 34). A reduced root system and low oxygen diffusion to the root seem to be the major factors involved. Letey et al (36) observed reduced mineral uptake of snapdragons due to low oxygen diffusion in the order of K>P>(Ca+Mg). In other studies with barley Letey et al (38, 41) found similar results except Ca and Mg were not greatly affected. Reduced N, P and K uptake were reported for Newport Kentucky bluegrass grown under low ODR (39). Waddington and Baker (74) found no effect of low ODR on N, P and K content.

Total Nonstructural Carbohydrates

Carbohydrate reserves or total nonstructural carbohydrates (TNC) are necessary for turfgrasses to withstand various stresses and recover from injuries (10). Nelson (56) reported that soil conditions caused by compaction can cause stomata on the under side of the leaf to be closed much of the time. The reduction of photosynthesis would soon leave the plant depleted of carbohydrates. Reduction of TNC levels have been reported for several turfgrass species subjected to compaction treatments (17, 18).

Drought and temperature hardiness are related to TNC levels (10). If carbohydrate reserves are depleted or at low levels the hardiness of the turfgrass will be reduced for both high or low temperatures and drought.

A thinner more open turf can lead to increased temperatures in the turf canopy, increasing the demand on the carbohydrate reserves of the plant. Youngner et al (84) concluded that TNC levels of Kentucky bluegrass were closely associated with temperature. Prolonged periods of high temperatures or short durations of very high temperatures showed a decrease in TNC levels. Watschke and Waddington (75) found that temperature stress could have a severe affect on turfgrass growth if it coincided with a TNC depletion.

Since a turf growing under compacted soil conditions is exposed to more stresses it is likely to have reduced TNC levels. Thus, its chance for recuperation is reduced when it is injured.

Water Relations

The increase in water retention and decrease in oxygen associated with soil compaction greatly affects plant water relations. Water transpired by plants is necessary for cooling. As much as 97 to 99 percent of water absorbed by the roots of turfgrass is transpired with only 1 to 3 percent utilized in plant metabolic processes (10). Reduced water uptake as a result of decreased root permeability (36, 50, 56) or rooting depth will increase the potential for high temperature and drought stress.

Several researchers have demonstrated that an increase in water film thickness around the root plus low soil oxygen levels reduce water use and result in plants more susceptible to high temperature stress (1, 5, 36, 38, 40, 42, 56, 63). Letey et al (36) found that when snapdragons were exposed to low soil oxygen levels plant cells were less turgid and the plant showed signs of wilting at midday. Similar findings were reported from a study using sunflowers (40). Sunflowers were also shown to be unable to survive air temperatures of $33^{o}C$ under low soil oxygen conditions (42). Low soil oxygen decreases root hydration which would cause an impedance to water flow in the plant (38). Aceves-N et al (1) reported decreases in transpiration rates of 54 and 65 percent in three varieties of wheat subjected to low oxygen levels.

Water use efficiency, ml H_2O per 1 g dry tissue, is not widely reported in the literature but evidence suggests that compaction may decrease water use efficiency. Anaya and Stolzy (5) noted decreased water use efficiency for wheat grain production at low oxygen levels.

Reduced infiltration and percolation on compacted turfsites increase the potential for other water related problems. Under high temperatures and standing water, scald injury can occur resulting in partial or complete kill of the turf. Another stress that may occur under waterlogged soil conditions is wet wilt. This is wilt that can occur even with adequate soil moisture. In the winter months standing water can increase crown hydration and make the turfgrass more susceptible to intracellular freezing.

Water stress or excess water can also increase development of many diseases, such as dollar spot, Fusarium blight, Pythium blight, red thread, and stripe smut (10). Excess moisture favors such diseases as Rhizoctonia brown patch and Pythium blight.

Other Responses

A turf of low density and reduced vigor growing under moist soil conditions is more prone to weed encroachment. Annual bluegrass, goosegrass, clover, and knotweed are known to invade compacted sites.

Seedling emergence may also be reduced by soil compaction due to increased soil strength and low oxygen diffusion rates (9, 64). In a study by Rahman et al (58) compaction delayed seedling emergence by up to five days and caused increased activity and residual of both atrazine and trifluralin. This could have been due to reduced leaching and microorganism activity. In an effort to overcome the detrimental effects of compaction on seedling emergence, Wilkins et al (80) investigated the growth regulating chemical 3,5 diiodo-4-hydroxybenzoic acid (DIHB). They found a positive response of 15 to 47 percent increases in root length of barley seedlings grown in compacted soil with DIHB incorporated, compared to the control.

Compaction Effects on the Water Cycle and Irrigation

The changes in soil physical properties and plant growth, caused by compaction, influence water management practices. Lower infiltration rates, decreased percolation, and increased runoff must be taken into consideration when irrigating compacted turfsites. These factors, along with reduced root and shoot growth, require that the turf manager know and understand his soil conditions and make appropriate adjustments in irrigation programing.

Water Cycle

The altered pore space of soils subjected to compaction causes reduced infiltration of water and increased runoff (9, 10, 70). Decreases in non-capillary pores markedly reduces infiltration rate. Watson (73) reported a decline in infiltration of a coarse sandy loam soil by 97 percent with a decrease in non-capillary pores of 50 percent when going from a bulk density of 1.31 to 1.64 g/cm^3. A nine year study of a golf green in Virginia demonstrated a decrease of 22 percent in air porosity accompanying a 46 percent decrease in infiltration rates when subjected to heavy compaction treatments compared to normal maintenance (22). Several investigations of compaction on turfgrass have demonstrated similar findings (15, 20, 44, 54).

Lower infiltration rates can increase the potential for evaporation losses. In order to compensate for low infiltration, water must be applied at a reduced rate and more frequently, thus increasing evaporative losses. Surface ponding is also more likely to occur and this would increase water lost by evaporation.

Periods of wet weather or over-irrigation may lead to leaching, wasting both water and fertilizer. Bauder and Schneider (8) observed a significant increase in NO_3-N leaching when using urea as a nitrogen source under excessive irrigation compared to optimum irrigation levels. Brown et al (14) found that NO_3-N leaching was reduced and N-use efficiency increased if irrigation was kept at or near evapotranspiration rates when using inorganic soluble sources of nitrogen. Irrigation by tensiometer has been shown to reduce leaching (71) but subsurface irrigation does not reduce leaching (52).

The shallow root system of turfgrass growing under compacted soil conditions makes the potential for leaching even greater. A turf manager should know the depth of penetration of his irrigation water and the rooting depth of his turfgrass in order to reduce nutrient, water, and energy losses.

<u>Irrigation Programing</u>

Irrigation is one of the most difficult aspects of turfgrass culture (10). Supplemental application of water from irrigation systems are needed to maintain a dense, high quality turfgrass, especially on recreational sites. Although most turfgrass managers irrigate regularly, turf irrigation has been more of an art than a science (83). Many rely on observation and experience to develop a good irrigation program.

Irrigation is a complex practice with many variables. It takes time, experience, and considerable knowledge to become an efficient irrigation programer. Good watering practices demand a knowledge of soils and their condition, type and condition of the turfgrass being irrigated, the irrigation system being used, awareness of weather conditions and how they affect plant growth and water use. Soil compaction adds to the complexity of irrigation programing because of its affects on soil physical properties and plant growth.

There are many variables that determine the quantity, rate, and timing of irrigation water. The quantity of water applied should be closely related to consumptive use or evapotranspiration which is most affected by climatic factors such as humidity, wind speed, temperature, daylength, and precipitation (11). Other variables involved are soil moisture, type and structure, type of plant cover (67) and plant density (33).

Application rates are primarily dependent on infiltration rates and the design of the irrigation system. Many soils have infiltration rates between .63 to 2.5 cm/hour (66). There is as wide a variability of application rates of irrigation systems as there are different infiltration rates of soils. Irrigation systems should be designed specifically for the particular soil condition (3) but in many instances conditions are too variable.

The timing of water application is also important. A commonly accepted generalization for agricultural soils calls for irrigation when 60 percent of the available water in the root zone is depleted (66). For turfgrass, just prior to visible wilting is the preferred time (10) but in most situations this is not possible. Other factors that must be taken into consideration are effects on disease activity, evaporation losses, and time the turfgrass is to be used.

Instruments to help measure soil moisture levels and various equations have been developed to help simplify irrigation needs. Several scientists have formulated equations based on climatic conditions to predict evapotranspiration rates. Among these scientists are; H. Oliver, H.L. Penman, W.D. Criddle with H.F. Blaney and C.W. Thornwaite. Haise (29) and Hillel (32) give a good discussion on methods of measuring moisture in the soil and the instruments used. Tensiometers are commonly used and have the advantage of being easily installed and read. They also don't require meters or calculations. Evaporation pans are also used as an aid in determining irrigation needs. Actual evapotranspiration is usually 70 to 80 percent of pan evaporation (83).

General concepts and practices of turfgrass irrigation have been around for a long time. In 1955 Hogan (28) presented two rules of turf irrigation that still apply today, water infrequently and water deeply. He stressed knowing soil type as related to water holding capacity and rooting depth of the turfgrass to be irrigated. He also warned that traffic on moist soils (near field capacity) will cause compaction of the soil surface resulting in a thin, weedy turf and reduced infiltration rates. Watson (76) did an early study of the interacting affects of different irrigation levels and soil compaction on a good quality fairway turf. Among his findings were; supplemental water is necessary for a high quality turf, excessive watering promotes shallow rooting and encourages weeds and disease, and moisture levels exerted a greater influence on turf quality than did soil compaction. Harper (30) continued Watson's work for three additional years and reported similar results.

Much later Watson (77) reported the relationship between mowing height and frequency with water requirements. He concluded that watering practices are a function of clipping height and root development. But no data was given to aid in irrigation programing other than very general statements.

Some definite guidelines were reported for two soil types with both cool and warm season grasses by Tovey et al (69). They demonstrated that for a cool season mixture of Kentucky bluegrass and various fescues grown on sandy loam soil two irrigations per week were needed and for the same mix grown on a loam soil only once a week was needed. Warm season grasses ('Tifway' and 'Tifgreen' bermudagrass) grew fine on both soil types with only one irrigation per week. In each case enough water was applied to bring the root zone to field capacity.

A long term study of different irrigation programs on both warm and cool season grasses was done by Youngner et al (83). Five irrigation treatments were applied; a control based on common practices, three automatic irrigations activated by tensiometers at different settings (15, 40 and 65 cb) and irrigation based on evaporation from a pan. There was a savings of 52 and 56 percent of applied water, compared to the control, with tensiometer guided irrigation activated at 40 and 65 cb, respectively, with warm season grasses. They also reported no difference in rooting depth or quality between treatments although more annual bluegrass was present in the control. However, the results for the cool season turfgrasses were quite different with a non-significant reduction in water use by the lowest tensiometer set treatment but not any of the other treatments. Reasons for the difference were; increased evaporation and decreased rainfall during the period, better water management by local turfgrass managers, and lower tensiometer settings for the two lower treatments (35 and 55 cb compared to 40 and 65 cb for warm season). The driest treatment resulted in poor quality but there was no difference between other treatments. They concluded that with the use of evaporation pans or tensiometers a significant savings in water without sacrificing turf quality was possible. Similar findings were reported when scheduling irrigations using evapotranspiration rates as a benchmark (4, 21).

Morgan et al (53) did a study relating irrigation scheduling to compaction with common bermudagrass. They noted that soil compactibility, evapotranspiration, and number of irrigations were greater under a set irrigation schedule compared to tensiometer guided irrigation. They concluded that reduced evapotranspiration rates due to compaction were probably due to difference in top growth.

There is a limited amount of information available concerning soil compaction related to irrigation practices. Of the work presented on this topic limited information on soil and plant responses are reported. Conservation measures in turfgrass irrigation are necessary and currently being practiced all over the country. A better understanding of irrigation as affected by soil compaction will aid in more efficient use of water.

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Turfgrass Growth and Water Use Under Different Soil Compaction and Irrigation Regimes.

K.J. O'Neil and R.N. Carrow

ABSTRACT

Soil compaction and efficient use of irrigation water are two important concerns of turfgrass managers. This field study examines the effects of soil compaction on growth and water utilization of a cool season turfgrass species under different irrigation programs.

A 2 year old stand of Poa pratensis L. 'Baron' on a fine, montmorillonitic mesic Aquic Arguidoll soil was subjected to four treatments. 1) 0X - no compaction, irrigated by tensiometer, 2) 30X - 30 passes per week with roller, irrigated by tensiometer, 3) 0X - no compaction, set irrigation, and 4) 30X - 30 passes per week with roller, set irrigation schedule. Irrigation was by either a set schedule of 3.8 cm per week or when a tensiometer placed 10 cm deep read 70 cbar 3.8 cm water was applied.

Soil compaction had no affect on root weight or distribution. Visual quality, shoot density, verdure, and percent total cover were all reduced by compaction while total nonstructural carbohydrates (TNC) were unaffected. Compaction increased bulk density and moisture retention but reduced aeration porosity at -0.1 bar. Irrigation treatment had no affect on any of these parameters.

Water use over the season was reduced by 27 and 50% for tensiometer treatments 1 and 2, respectively compared to set schedule treatments 3 and 4 without a reduction in plant quality. Compacted plots utilized 8% less water than uncompacted plots when measured over a 9 day period

in midsummer. Over the period of the study in the tensiometer scheduled plots, the uncompacted treatment used 31.5 cm of water and the compacted treatment 21.8 cm. Thus, tensiometer guided irrigation was most efficient but compacted and uncompacted sites should be irrigated on separate schedules.

Additional key words: Kentucky bluegrass, Poa pratensis, root growth, tensiometer.

Foot and vehicular traffic are problems on recreational turfgrass sites. One of the major responses to traffic is compaction of the soil surface. Compaction alters the soil physical properties which in turn influence plant growth and water management.

Detrimental effects on turfgrass growth attributed to soil compaction are decreased root growth (3, 7, 12), decreased shoot growth (18, 20), reduced carbohydrate reserves (5, 6), and a decline in overall quality (3, 5, 6, 7). The major soil physical changes are reduced aeration porosity (3, 4, 5) increased bulk density (6, 7, 21), increased soil strength (21), and altered pore size distribution (3, 5, 7).

Watson (22) conducted a study on the interacting effects of compaction and irrigation levels. He concluded that moisture levels influenced turf quality more than soil compaction. Harper (9) continued Watson's work and made similar conclusions. Morgan et al (15) noted reduced evapotranspiration (ET) rates due to compaction and increased soil compactibility under a set irrigation schedule compared to tensiometer guided irrigation. There was also a decrease in the number of irrigations in the tensiometer guided treatments due to compaction. They attributed reduced ET rates of the compaction treatments to reduced top growth. Other irrigation work has been done under non-traffic conditions (1, 8, 19, 23).

The objectives of the study were to determine the effects of compaction on water utilization and turfgrass growth under different irrigation treatments.

MATERIALS AND METHODS

This study was done on 2 year old Poa pratensis L 'Baron' Kentucky bluegrass. The soil was a Chase silt loam (fine, montmorillonitic, mesic Aquic Arguidolls) with 19.6% sand, 60.7% silt, 19.7% clay, pH 7.3 and 3% organic matter. The study was conducted at KSU turf research plots in Manhattan, Kansas from 1 July to 6 Oct. 1980. Plots measured 1.12 m x 4.57 m with 3 replications per treatment. A 2 x 2 factorial, randomized complete block design was used. All treatments received .48 Kg N/100m^2 on 23 May and 18 July as urea and Milorganite, respectively. Mowing was done as needed at 6.3 cm with clippings returned.

The 4 treatments were 1) OX - no compaction, irrigation based on tensiometer, 2) 30X - compaction, irrigation based on tensiometer, 3) OX - no compaction, set irrigation schedule and 4) 30X - compaction, set irrigation schedule. Compaction levels were OX - no compaction and 30X - 30 passes per week with a smooth power roller. After 2 weeks compaction was reduced to 10 passes every other week to minimize wear and maintain the initial level of compaction. Tensiometers were installed in each treatment at 10 and 20 cm depths. The irrigation programs were: a set schedule of 3.8 cm per week including rainfall, and 3.8 cm when the tensiometer at the 10 cm depth read approximately 70 cbar.

Each plot was enclosed with 10 cm steel edging, 5 cm deep and flood irrigated with the proper amount of water. All compaction treatments were done 24 hours after irrigation. Static pressure exerted by the roller was 2.5 kg/cm^2 which is similar to the force received on recreational turfsites (2).

Soil physical measurements were made at the end of the study to measure the effects of compaction. Bulk density, aeration porosity, and moisture retention were determined from one core (5.4 diam x 6 cm) per plot. The 6 cm core was divided into two 3 cm zones to measure how deep compaction treatments affected soil physical properties. Verdure, shoot density and total nonstructural carbohydrates (TNC) were determined from 2 samples (5.4 cm diam) per plot. Samples collected before 1000 hours, oven dried at 100 C for 1 hour and then 60 C for 24 hours. TNC levels were determined by the method of Morris (17). Visual quality ratings were based on turf density, color, and uniformity. A scale of 9 = ideal, 6.5 = acceptable, 1 = no live turf, was used. Percent turf cover was based on visual observations. Root weights were determined by combining 4 cores (2 cm diam x 20 cm) per plot. Samples were divided in 5 cm zones, washed, dried at 60 C for 24 hours and weighed.

RESULTS AND DISCUSSION

Soil Physical Responses

Soil physical properties were affected by compaction but not by irrigation (Table 1). In the top 3 cm of soil, all properties measured were significantly altered. The 3 to 6 cm zone changed very little. The compaction in this study was similar to that occurring on recreational turf which is confined to the surface 2 to 3 cm (2, 6, 16).

Under compaction bulk density increased from 1.28 to 1.38 g/cm^3 when averaged over the irrigation treatments. Also, the moisture release curve was altered resulting in a reduction of non-capillary pores while capillary pore space increased. In a study where turfgrasses were subjected to compaction, Cordukes (7) reported a 6% increase in bulk density and a marked influence on the pore size distribution.

Aeration porosity was determined at -0.10 bar moisture since the turf was considered to have been subjected to this level of aeration most often due to the frequency of irrigation and slow drainage. Aeration porosity at -0.10 bar declined with compaction from 18.1 to 12.5%. Similar reductions in aeration porosity with increased bulk density have been noted by other researchers (3, 4, 5, 7, 21). Aeration porosity is generally considered to be limiting for plant growth at below 10% of the soil volume (10), which is close to the aeration of the compacted treatments at -0.10 bar. Since measurements were made in Oct., some of the effects of compaction may have dissipated.

Turfgrass Growth Responses

Soil compaction is often referred to as a hidden stress because effects on plant growth are not immediately visible and are always indirect. The altered soil physical properties influence aeration, strength, density and moisture status which may in turn affect plant growth and irrigation practices.

Shoot Growth. All visual quality ratings tended to be low due to prolonged periods of very high temperatures (Table 2). Compaction reduced visual quality ratings within 3 weeks on both tensiometer and set irrigation regimes. Under compaction the quality ratings were below the acceptable minimum of 6.5 for a good turf sod. No difference in turf quality was apparent between irrigation treatments.

The decline in visual quality with compaction has been observed by many investigators (3, 4, 5, 6, 7, 18). Aside from Boufford and Carrow (3) and Carrow (5, 6), wear was present in these studies and contributed significantly to decline in quality. Contributing to reduced quality under compaction, was a reduction in percent turf cover (Table 2). Visual quality has been found to be an indicator of compaction stress on Kentucky bluegrass. Carrow (5) reported a correlation coefficient of 0.75 for visual quality versus bulk density.

Except for the Sept. measurement, shoot density declined with compaction. Irrigation treatments had no effect (Table 2). The consistently high air temperatures of above 38 C for July and Aug. placed all grasses under high temperature stress. This may have masked compaction responses and account for the similar density readings for all treatments in Sept. As the temperature began to moderate in late Sept. and Oct., compacted plots again demonstrated reduced density. Although there was a reduction in plant density the individual plant weights were similar.

Verdure decreased with compaction by 21 to 35% when averaged over irrigation regimes (Table 2). Decreased density and verdure result in a thinner, more open turf which reduces wear tolerance (2) and the turfgrass is more susceptible to high temperature stress and weed invasion.

Decreased density and verdure under compaction have been demonstrated by other investigators (4, 5, 6, 18) but increased density (5, 22) and no response (3) have also been found. Generally, reduced shoot densities occur under moderate to severe compaction and during less favorable growing periods.

Total nonstructural carbohydrates are important to turfgrass since low levels reduce hardiness and recuperative potential when a turf is injured. Neither compaction or irrigation regime influenced TNC levels for the two sampling periods (Table 2).

Root Growth. Root weights and distribution were not affected by either compaction or irrigation treatments (Table 3). This study began in July when root growth of the cool season grass had already occurred. Thus, the 25 Aug. rooting data would reflect root deterioration instead of any influence on root growth. While no treatment affected root deterioration in the summer months, trends began to appear by the Oct. sampling. Compaction responses to root growth at that time were significant at the 10% level for both the total root weights and 5-10 cm zone. Irrigation treatments also began to exhibit differences. There was a significant decrease at the 12% level for total root weights with the set irrigation treatment. Much more water was being applied, keeping the soil very moist. Lower aeration porosity may account for the decrease in rooting.

Decreased rooting with compaction is commonly reported (3, 4, 5, 6, 7, 12, 18). Irrigation treatments also affect rooting. Watson (22) found that the deepest root system of a mixture of cool season grasses was with no supplemental irrigation but an unacceptable quality turf occurred. No difference was observed between as needed irrigation (approx. 16 to 18% moisture content) and moisture levels kept at or near field capacity (approx. 24% moisture content). A saturated irrigation treatment produced the shallowest root system.

Water Use

Tensiometer irrigated plots resulted in a water savings of 27 and 50% over the period of the study for the uncompacted and compacted treatments, respectively, when compared to the set irrigation treatments (Table 4). The greatest savings was in the fall with a reduction of 70 and 85% of applied water for the uncompacted and compacted treatments respectively. Other investigators have demonstrated water savings with tensiometer guided irrigation (15, 23). Youngner et al (23) observed savings of 52 and 56% for tensiometer guided irrigation activated at 40 and 65 cbar respectively for warm season grasses under non-traffic conditions. They attributed the savings to tensiometers being more responsive to changing weather patterns than a visual estimation of water needs. Irrigation applied at or near the evapotranspiration rate can result in a substantial water savings without a reduction in plant quality (1, 8).

Compaction reduced the quantity of water used by 31% over the study period for the tensiometer irrigated plots. This is possibly due to reduced growth and a less viable root system. Increased moisture retention will increase water film thickness surrounding the root. A reduction in oxygen diffusion to the root and permeability with increasing water film thickness will decrease water use (14). Letey et al (13) noted the greatest water use for barley was under high oxygen levels and that low oxygen levels decreased root hydration causing increased impedance to water flow in the plant.

Following a heavy rain in Aug., water use was measured for a 9 day period. Plots irrigated on a set schedule utilized approximately 15% more water than tensiometer irrigated plots. The turf grown under set irrigation appeared to extract a greater quantity of water from all soil zones measured. Visual quality ratings and verdure were slightly higher near those dates and possibly somewhat more growth occurred. Turfgrass will also use more water if kept under moist conditions (11).

During the 9 day period, the compacted plots utilized 8% less water compared to the uncompacted plots (Table 4). Reduced water extraction for the compacted treatments was particularly apparent in the surface 0-3 cm zone where most of the compaction effect occurred. The reduction in water use on compacted plots may be a result of decreased turf growth rate, less plant material per unit area, and a decrease in plant available moisture in the 0-3 cm zone after compaction.

Recreational turf requires a high quality sod which must be irrigated in order to maintain quality and adequate growth rate to recover from wear. The adverse effects of compaction on soil physical properties can result in decreased turf vigor and influence irrigation practices.

In the present study the compacted sites utilized 31% less water over a season compared to uncompacted when water was applied by tensiometer programing. During a hot, dry midsummer period water was reduced by 8%. This suggests that irrigation on heavily compacted areas should be carefully programed to avoid excessive water use. For example, the turfgrass in the compacted center of a football field may utilize less water than the sides due to a reduction in turf stand and growth as well as altered moisture release from the soil. Each area would best be irrigated separately. An irrigation system should have a separate zone for the center of the field so that it may be programed differently from the less intensively used areas.

Utilization of tensiometers for irrigation programing versus a set schedule resulted in water savings of 27 to 50% over the course of the study. In midsummer water savings were 15% over a nine day period. This occurred without a reduction in turf quality. Thus, irrigators can effectively use tensiometers in order to irrigate more efficiently. However, a tensiometer placed in an uncompacted site will not correctly indicate water needs of an adjacent compacted area since turf and soil conditions will be different.

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Table 1. Bulk density, aeration porosity, and moisture retention measurements on 8 Oct 1980.

Soil physical property	Treatment+				L.S.D. (0.05)‡		
	NC-T	C-T	NC-S	C-S	(C)	(I)	(CxI)
Bulk density (g/cm^3)							
0-3 cm	1.26	1.36	1.29	1.39	.05	ns	ns
3-6 cm	1.31	1.33	1.31	1.36	ns	ns	ns
Aeration porosity (-0.1 bar, %)							
0-3 cm	18.5	10.8	17.7	14.2	2.1	ns	ns
3-6 cm	12.5	13.9	15.6	14.4	ns	ns	ns
Moisture content by volume (%)							
0-saturation	.54	.51	.57	.54	ns	ns	ns
-0.10 bar	.35	.40	.39	.40	.03	ns	ns
-0.33 bar	.33	.37	.35	.37	.01	ns	ns
-1.0 bar	.32	.36	.34	.36	ns	ns	ns
-2.0 bar	.30	.35	.32	.36	.02	ns	ns

+ NC = No compaction, C = compaction, T = irrigated by tensiometer, S = irrigated on a set schedule.

‡ C = compaction, I = irrigation.

Table 2. Visual quality, percent turf cover, shoot density, verdure, individual shoot weight, and total nonstructural carbohydrates (TNC) measurements.

Growth characteristic	Treatment+ NC-T	C-T	NC-S	C-S	L.S.D. (0.05) (C)	(I)	(CxI)
Visual quality							
3 July	7.0	---	---	---	---	--	--
21 July	6.8	5.3	6.8	5.7	.61	ns	ns
8 Sept	7.1	5.8	7.4	5.9	.55	ns	ns
6 Oct	6.8	5.7	7.3	6.1	.87	ns	ns
% Turf coverage							
30 July	98	---	---	---	---	--	--
6 Oct	95	85	96	88	6	ns	ns
Shoot density (shoot/100cm^2)							
3 July	118	---	---	---	---	--	--
31 July	122	92	131	83	18	ns	ns
5 Sept	100	100	109	79	ns	ns	ns
14 Oct	96	65	100	70	21	ns	ns
Verdure (g/100cm^2)							
8 July	1.52	---	---	---	---	--	--
8 Sept	1.94	1.58	2.20	1.68	.27	ns	ns
15 Oct	2.12	1.15	2.08	1.59	.50	ns	ns
Individual shoot weight (mg/shoot)							
8 Sept	20.2	18.3	20.1	22.0	ns	ns	ns
4 Oct	22.2	17.8	21.9	26.6	ns	ns	ns
% TNC							
8 July	20.9	---	---	---	---	--	--
8 Sept	32	32	23	25	ns	ns	ns
5 Oct	38	35	37	40	ns	ns	ns

+ NC = No compaction, C = compaction, T = irrigated by tensiometer, S = irrigated on a set schedule.

Table 3. Total root weight and root distribution.

Measurement	Treatment+				L.S.D. (0.05)		
	NC-T	C-T	NC-S	C-S	(C)	(I)	(CxI)
Total root weight 0-20 cm (g/100cm^2)							
3 July	2.05	----	----	----	--	--	--
25 Aug	2.12	2.22	2.19	2.15	ns	ns	ns
6 Oct	2.30	1.65	1.57	1.40	ns	ns	ns
Root weight 0-5 cm (g/100cm^2)							
3 July	1.12	----	----	----	--	--	--
25 Aug	1.33	1.28	1.09	1.35	ns	ns	ns
6 Oct	1.34	0.90	0.76	0.86	ns	ns	ns
Root weight 5-10 cm (g/100cm^2)							
3 July	.46	----	----	----	--	--	--
25 Aug	.36	.48	.55	.37	ns	ns	ns
6 Oct	.48	.28	.32	.21	ns	ns	ns
Root weight 10-15 cm (g/100cm^2)							
3 July	.26	----	----	----	--	--	--
25 Aug	.25	.27	.32	.26	ns	ns	ns
6 Oct	.27	.26	.28	.15	ns	ns	ns
Root weight 15-20 cm (g/100cm^2)							
3 July	.21	----	----	----	--	--	--
25 Aug	.18	.19	.23	.17	ns	ns	ns
6 Oct	.21	.21	.21	.18	ns	ns	ns

+ NC = No compaction, C = compaction, T = irrigated by tensiometer, S = irrigated on a set schedule.

Table 4. Seasonal water applied and water use measurements for 16 Aug to 25 Aug.

Measurement	Treatment+				L.S.D. (0.05)		
	NC-T	C-T	NC-S	C-S	(C)	(I)	(CxI)
Seasonal water applied (cm)							
1 July - 14 July	6.1‡	1.8	7.6	7.6			
15 July - 31 July	10.2	10.2	11.4	11.4			
1 Aug - 14 Aug	7.6	3.8	7.6	7.6			
15 Aug - 31 Aug	3.8	3.8	3.8	3.8			
1 Sept - 14 Sept	3.0	0	6.9	6.9			
15 Sept - 30 Sept	0	0	3.8	3.8			
1 Oct - 6 Oct	0	2.2	2.2	2.2			
Total	31.5	21.8	43.2	43.2			
Water use (cm) 16 Aug - 25 Aug							
0 - 3cm soil zone	.66	.43	.67	.52	.01	.01	.01
4 - 10cm soil zone	1.13	1.18	1.39	1.29	.01	.01	.02
11 - 20cm soil zone	1.60	1.66	1.99	1.81	.02	.02	.02
Total 0 - 20cm	3.39	3.27	4.05	3.60	.02	.02	.03

+ NC = No compaction, C = compaction, T = irrigated by tensiometer, S = irrigated on a set schedule.

‡ Treatments NC-S and C-S received the same quantities of water by design. Therefore, only paired comparisons of treatments were made. Significant differences occured for the season between NC-T vs C-T, NC-T vs NC-S, and C-T vs C-S.

TABLE CAPTIONS

Table 1. Bulk density, aeration porosity, and moisture retention measurements on 8 Oct 1980.

Table 2. Visual quality, percent turf cover, shoot density, verdure, individual shoot weight, and total nonstructural carbohydrates (TNC) measurements.

Table 3. Total root weight and root distribution.

Table 4. Seasonal water applied and water use measurements for 16 Aug to 25 Aug.

Turfgrass Growth, Water Use, and Soil Aeration Status Under Soil Compaction

K.J. O'Neil and R.N. Carrow

ABSTRACT

Soil compaction is a serious problem on recreational turfgrass sites. This greenhouse study examines the effects of soil compaction on turfgrass growth, water utilization, and soil aeration.

Lolium perenne L. 'Derby' was subjected to 3 compaction levels 1) 0 blows - no compaction, 2) 5 blows - moderate compaction and 3) 10 blows - heavy compaction. Compaction treatments were done by dropping a 11.5 Kg weight from a height of 65 cm. When tensiometers installed at a depth of 5 cm read 65 cbar for treatment 1, 5 cm of water was applied.

Soil compaction increased bulk density, reduced aeration porosity, visual quality, shoot density and total root weights, altered root distribution and had no effect on verdure and individual shoot weight. Total clipping weights were reduced by 38 and 53% for the moderate and heavy compaction treatments, respectively.

Water use over the study was reduced by 21 and 49% for the moderate and heavy compaction treatments, respectively. Heavy compaction levels had oxygen diffusion rates (ODR) below 20 x 10^{-8} g $cm^{-2}min^{-1}$ for at least 53 hours after irrigation. The uncompacted and moderate compaction achieved acceptable ODR levels before 29 hours. Since compaction reduced rooting, slowed shoot growth, and increased moisture retention, the soil remained at a reduced aeration status for a longer period of time.

Additional key words: Perennial ryegrass, Lolium perenne, root growth, oxygen diffusion, ODR.

Soil compaction on recreational turfgrass sites is a serious problem for turfgrass managers. The altered soil physical properties caused by compaction influence plant growth and irrigation management.

The major soil physical changes are reduced aeration porosity (5, 6) increased bulk density (4, 5, 6, 20), increased soil strength (20, 22) and altered pore size distribution (4, 5). Detrimental effects on turfgrass growth attributed to soil compaction are decreased root growth (6, 18), decreased shoot growth (18, 19) reduced carbohydrate reserves (5) and decline in overall quality (3, 4, 5, 6).

Morgan et al (15) noted decreased water use under compacted soil conditions and reduced evapotranspiration (ET) compared to uncompacted treatments. They attributed lower ET rates to a decline in top growth. Less water use has been observed by many investigators under low soil oxygen conditions to simulate a compacted environment (1, 2, 8, 12, 16). Letey et al (8) exposed growing media to different oxygen levels ranging from less than 1 to 21% and observed decreased water use of snapdragons with lower oxygen levels. Reduced water use was attributed to less root surface area and decreased permeability. Sojka et al (16) noted stomatal closure at low oxygen levels, thus reducing water use. Reduced rooting, a common response to soil compaction (4, 5, 6, 9, 18, 20, 23) would also be expected to decrease water use but specific work is limited.

Soil compaction reduces aeration porosity (4, 5, 6). Aeration porosity is an indirect but helpful measure of soil oxygen status. A more realistic approach is to measure oxygen diffusion rates (ODR). In the platinum microelectrode method (7) the electrode acts as a localized oxygen sink and simulates a small respiring root or organism. Several investigators have found that low ODR levels restrict root growth (9, 11, 12, 13, 21, 22, 23). However, limited research on ODR levels and fluccuations under compacted conditions are reported.

Lunt (14) found ODR values at or near zero 24 hours after irrigation 6.5 cm below the compacted surface of several turfgrass sites. Extensive work has been done by Wijk (22, 23) on ODR under compacted conditions but ODR readings were not taken at specified times after irrigation or rainfall. Thus, the relationship between ODR levels and compaction were unclear.

The objectives of this study were to determine the effects of soil compaction on turfgrass growth, water utilization, and soil aeration.

MATERIALS AND METHODS

This study was conducted in a greenhouse using a soil mix of one part sand to two parts soil, a Chase silt loam (fine, montmorillonitic, mesic Aquic Arquidolls). Pots were 30.5 cm diam PVC pipe cut to a length of 76.2 cm. A plastic plate with a hole in the center for drainage was placed 1.25 cm from the bottom. A 5 cm layer of gravel was placed in the pot before filling with the soil mix. Pots were seeded with <u>Lolium perenne</u> L. 'Derby' on 12 Dec. 1980 at a rate of 3.9 Kg/100 m^2. The grass was grown under lights with a 16 hour daylength and temperature of 21 t0 27^oC in the day and 18 to 21^oC at night. The mowing height was 10 cm.

All pots received compaction treatments on 6 Feb. 1981, 24 hours after 5 cm of water had been applied. Three compaction treatments were applied; 1) 0 blows - no compaction, 2) 5 blows - moderate compaction and 3) 10 blows - heavy compaction. Compaction treatments were done by dropping a 11.5 Kg weight from a height of 65cm onto a piece of wood cut to fit the inside diameter of the pot. A maintenance compaction of 2 blows and 4 blows from a height of 10 cm for treatments 2 and 3 respectively were applied every two weeks.

One tensiometer and three platinum microelectrodes were placed at 5, 10, and 25 cm depths for each pot. All treatments were irrigated when the tensiometer at the 5 cm depth in treatment 1 read 65 cbars. Each treatment was replicated 3 times, a completely randomized block design was used.

Soil physical measurements were made at the end of the study in April. Bulk density, aeration porosity and moisture retention were obtained from one core (5.4 cm diam x 6 cm) per pot. Each sample was divided into two 3 cm zones to determine the depth to which compaction influenced the soil physical properties. Verdure and shoot density were from two samples (5.4 cm diam) per pot. Clippings were collected after every mowing. Samples of verdure and clippings were dried at 60 C for 24 hours before weighing. Root weights were determined by combining four cores (2 cm diam x 25 cm) per pot, then divided into 3 zones, washed, dried at 60 C for 24 hours and weighed. Visual quality was based on turfgrass color and density. A scale of 9 = ideal, 6.5 = acceptable, 1 = no live turf was used. Oxygen diffusion rate (ODR) measurements were made by the platinum microelectrode method (7). Three readings per depth were averaged together. Readings were determined at several intervals after irrigation to determine ODR fluccuations over time.

RESULTS AND DISCUSSION

Soil compaction had a significant influence on soil physical properties. Bulk density increased from 1.40 (uncompacted), to 1.49 and 1.57 g/cm^3 for the moderate and heavy compaction treatments, respectively. Aeration porosity at -0.10 bar was reduced from 25 (uncompacted) to 21, and 17% for the moderate and heavy compaction treatments respectively. A change in the moisture release curve denoted an alteration of pore size distribution which should affect moisture retention, aeration, and infiltration. Standing water was observed 6 to 10 hours after irrigating the heavily compacted treatments. Thurman and Pokorny (18) noted surface water in excess of .3 cm for periods of 24 to 48 hours after irrigating compacted soils.

Growth Responses

Shoot Growth. Visual quality declined in the compacted pots 10 days after treatments (Table 1). Some blades were crushed by the initial compaction treatment but wear was not a factor with maintenance compaction thereafter. The visual quality ratings did not go below the acceptable level of 6.5 for a good quality turf sod until the last 2 weeks of the experiment. A slight infestation of *Septoria* leaf spot began to contribute to the decline in quality at that time. Prolonged periods of low soil aeration conditions may also have contributed to the low ratings.

A delayed response to shoot density was observed (Table 1). By the final measurement in Apr., both compaction levels caused a reduction in plant density. The 20 Mar reading noted a substantial increase in density for the moderately compacted treatment. Carrow (5) observed a similar response for *Lolium perenne* L. 'Pennfine' perennial ryegrass, with an increase in density under moderate compaction and then a decline with a further increase in compaction. The individual shoot weights for that date were not significantly different but tended to be lower for the moderate compaction level (Table 1). That treatment was developing many small tillers at that time but they did not mature as can be seen from the decline in density by the next reading. Low oxygen levels have been reported to reduce tillering (1, 16).

Verdure was not affected by compaction (Table 1). It is interesting to note that larger differences occurred for the Apr. measurement, similar to the density response. If the study had continued for a longer period of time compaction may have influenced verdure. Decreased verdure under compaction has been reported (5, 18) but no response has also been observed (4).

Soil compaction did reduce clipping weights throughout the duration of the experiment (Table 1). Total clipping weights were reduced by 38 and 53% for the moderate and heavy compaction treatments, respectively, compared to the uncompacted treatments. A very similar response of 'Tifgreen' bermudagrass (*Cynodon dactylon* L.) was reported by Thurman and Pokorny (18).

Nutrient uptake and ratios have been reported to be altered by compacted conditions (19). In general, the reduction in uptake is in the order K>N>P>Ca>Mg (17). Near the completion of the study plant N, P, and K levels were determined. No difference due to compaction were observed with N, P, and K levels at 3.46, 0.37, and 3.73%, respectively (Appendix A-1). Waddington and Baker (21) looked at nutrient levels in Kentucky bluegrass (*Poa pratensis*) under various oxygen levels and reported no difference.

Root Growth. Total root weight was not significantly affected by compaction (Table 2) at the 5% level but tended to decrease with compaction. The 20 Mar root weight determinations revealed a significant decline in rooting with compaction at the 10% level.

Root distribution was affected by compaction. A higher percentage of roots occurred in the surface 0-5 cm and a lower percentage in the 10-25 cm zone for the heavy compaction treatment.

The difference in root weights and distribution were probably due to low aeration status and higher soil strength. Low oxygen levels can restrict root growth of turfgrass and other plants (12, 22, 23, 25, 26, 62).

Water Use

Water use was reduced over the course of the experiment by 21 and 49% for the moderate and heavy compaction treatments respectively, compared to no compaction (Table 3). The greatest reduction in water extraction was from the 0-5 and 5-10 cm zones. By the end of the study there was a significant reduction in water extraction in the 10-25 cm zone for the heavy compaction treatment, which may have been due to the large decrease of root growth in the lower soil zone. Reduced water use under low soil oxygen levels has been reported (1, 2, 8, 12, 16). Reduced rooting, slower shoot growth, and lower aeration may all have contributed to reduced water use.

Water use efficiency, ml of water needed to produce 1 g dry tissue, was measured and no significant differences were noted (Table 4). The no compaction treatment did tend to demonstrate better water use efficiency.

Soil Aeration

Compaction was found to significantly reduce ODR values (Table 5). Readings below the value commonly reported to be limiting to plant growth, 20×10^{-8} g cm^{-2} min^{-1} (13) were found 53 hours after irrigation for the heavy compaction treatment. In contrast, the uncompacted treatments achieved acceptable ODR levels before 29 hours. Values at the 29 hour reading were lower for the heavy compaction treatment than the 5 hour values. This may have been due to air trapped in the soil pores since infiltration was very slow in this treatment. Similar data was collected for a second period of 81 hours from 13 Apr. (Appendix A-2).

Tensiometer values are presented in Table 5 at 101 hours. Much lower matrix potentials were observed for long periods after irrigation in the heavy compaction treatment. The increased water content of the soil would account for the lower ODR readings. Also, since root growth was reduced and plant growth slower, less water would be extracted from the soil leaving a higher moisture content for longer periods of time compared to a vigorously growing turf with a more extensive root system (ie. the no compaction treatment).

Critical ODR values have been reported for various grasses. An ODR of 20×10^{-8} g cm^{-2} min^{-1} has been observed to restrict rooting of Newport Kentucky bluegrass (11). Waddington and Baker (21) found much lower values of 5 to 9, and 3×10^{-8} g cm^{-2} min^{-1} for Merion Kentucky bluegrass and Penncross creeping bentgrass (*Agrostis palustris* Huds.), respectively. Wijk (22, 23) noted above ground growth was reduced by ODR values less than 10×10^{-8} g cm^{-2} min^{-1} and root growth at 7.5×10^{-8} g cm^{-2} min^{-1} of a perennial ryegrass and annual bluegrass (Poa annua) mix growing under compacted soil conditions.

Reduced shoot growth, altered root growth and distribution, and soil physical changes due to compaction would be expected to influence soil moisture status. This in turn affects water use and soil aeration. Less water is extracted by a plant with a reduced or restricted root system and slower shoot growth, thereby contributing to decreased aeration.

The present investigation illustrates that soil aeration is markedly reduced under heavy compaction. Once the soil is saturated, an acceptable oxygen status may not be achieved for 2 to 3 days and root function would be impaired during this period. Thus, proper irrigation programing is particularly important under compacted conditions. Avoiding light, frequent irrigation would be important. Irrigations should be as infrequent and as deep as the root system would allow. Also, cultivation to improve drainage would be helpful.

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Table 1. Visual quality, shoot density, verdure, individual shoot weight and clipping measurements.

Growth characteristic	Compaction level None	Moderate	Heavy	L.S.D. (0.05)(C)
Visual quality				
3 Feb	9	---	---	----
13 Feb	9	8.3	7.6	0.39
10 Mar	8.6	8.0	7.5	0.67
30 Mar	8.6	8.1	7.8	0.52
17 Apr	6.8	6.0	5.2	1.20
Density (shoots/100cm^2)				
16 Feb	166	---	---	----
20 Mar	153	197	170	ns
27 Apr	162	135	131	15
Verdure (g/100cm^2)				
16 Feb	0.96	---	---	----
20 Mar	2.77	2.78	2.52	ns
27 Apr	2.54	1.59	1.70	ns
Individual shoot weight (mg/shoot)				
16 Feb	5.8	---	---	----
20 Mar	18.1	14.2	14.7	ns
27 Apr	15.6	11.8	12.8	ns
Clippings (g/100cm^2)				
5 Feb - 4 Mar	0.67	0.48	0.32	0.27
4 Mar - 24 Mar	1.11	0.66	0.50	0.47
24 Mar - 13 Apr	0.75	0.42	0.31	0.27
5 Feb - 13 Apr	2.53	1.56	1.13	0.87

Table 2. Total root weights and percent distribution by depth.

Measurements	Compaction level			L.S.D. (0.05)(C)
	None	Moderate	Heavy	
Total root weight 0-25cm (g/100cm^2)				
16 Feb	0.65	---	---	--
20 Mar	0.39	0.31	0.24$^+$	ns
28 Apr	0.96	0.80	0.78	ns
% Roots in 0-5cm zone				
16 Feb	39(.25)‡	---	---	--
20 Mar	41(.16)	61(.19)	75(.18)	ns
28 Apr	45(.43)	53(.42)	68(.53)	13
% Roots in 5-10cm zone				
16 Feb	23(.15)	---	---	--
20 Mar	18(.07)	10(.03)	13(.03)	ns
28 Apr	19(.18)	15(.12)	14(.11)	ns
% Roots in 10-25 cm zone				
16 Feb	38(.25)	---	---	--
20 Mar	41(.16)	29(.09)	12(.03)$^+$	ns
28 Apr	36(.35)	32(.26)	18(.14)*	8

+ Significant at the 10% level.
‡ Number in ( ) is root weight found in that zone (g/100cm^2).
* Significant at the 5% level.

Table 3. Total water use and extraction from 3 depths.

Time Period	Compaction level None	Moderate	Heavy	L.S.D. (0.05)(C)
5 Feb - 4 Mar	---	cm H_2O	---	
0 - 5cm	1.6	1.4	1.1	0.3
5 - 10cm	1.6	1.4	1.1	0.3
10 - 25cm	4.8	4.8	4.8	ns
Total	8.0	7.6	7.0	0.6
4 Mar - 24 Mar				
0 - 5cm	4.8	4.2	3.1	0.2
5 - 10cm	4.8	3.9	2.8	0.3
10 - 25cm	13.9	12.4	7.2	ns
Total	23.5	20.5	13.1	6.9
24 Mar - 13 Apr				
0 - 5cm	4.8	4.1	3.1	0.2
5 - 10cm	4.5	3.0	1.5	1.5
10 - 25cm	10.8	5.5	1.7	6.5
Total	20.1	12.6	6.3	7.9
5 Feb - 13 Apr				
0 - 5cm	11.2	9.7	7.3	0.4
5 - 10cm	10.9	8.3	5.4	1.8
10 - 25cm	29.5	22.7	13.7	ns
Total	51.6	40.7	26.4	14.2

Table 4. Water use efficiency.

Compaction level	5 Feb-4 Mar	4 Mar-24 Mar	24 Mar-13 Apr	5 Feb-13 Apr
	ml H_2O/g tissue			
1. None	1.68	2.99	3.69	2.85
2. Moderate	2.54	4.47	4.35	3.86
3. Heavy	3.04	4.36	3.67	3.60
L.S.D. (0.05) (C)	ns	ns	ns	ns

Table 5. Oxygen diffusion rates (ODR)[+] from 18 Mar to 22 Mar for 3 depths.

Compaction level	5 hours[‡]			29 hours			53 hours			77 hours			101 hours		
	5cm	10cm	25cm	5cm	10cm	25cm	5cm	10cm	25cm	5 cm	10 cm	25cm	5cm	10cm	25cm
	$g \times 10^{-8} cm^2/min$														
1. None	20	18	38	27	37	36	36	52	47	46	65	53	57(35)	76(28)	78(11)[§]
2. Moderate	21	10	19	38	34	42	49	41	49	50	53	51	74(25)	69(15)	65(12)
3. Heavy	12	14	25	5	17	11	14	18	15	34	19	22	47(9)	31(7)	34(4)
L.S.D. (0.05) (C)[¶]	ns	ns	ns	29	ns	11	18	ns	29	ns	34	ns	ns	25	ns

[+] Each value is the average of 9 electrode readings.
‡ Hours after irrigation.
§ Matrix potential (cbar) at the time of reading the 101 hour ODR values.
¶ Based on 10% F-test due to high variability of ODR readings.

TABLE CAPTIONS

APPENDIX

APPENDIX

Table A-1. Percent nitrogen, phosphorous and potassium found in clippings from 1 April - Greenhouse Study.

Compaction level	N	P	K
		%	
1. None	3.4	.36	4.0
2. Moderate	3.6	.35	3.6
3. Heavy	3.4	.38	3.6

Table A-2. Oxygen diffusion rates (ODR)[+] from 13 Apr - 16 Apr for 3 depths - Greenhouse Study.

Compaction level	9 hours[‡]			33 hours			57 hours			81 hours		
	5cm	10cm	25cm	5cm	10cm	25cm	5cm	10cm	25cm	5cm	10cm	25cm
	----------	----------	----------	----------	----------	$g \times 10^{-8}$	cm^2/min	----------	----------	----------	----------	----------
1. None	38	39	40	42	49	51	51	69	74	76(18)[§]	85(22)	83(5)
2. Moderate	38	22	21	47	29	30	68	51	39	108(24)	85(10)	43(8)
3. Heavy	12	17	14	7	8	12	71	46	26	103(17)	89(9)	32(3)
L.S.D. (0.05) (C)[¶]	ns	20	24	26	18	17	ns	ns	ns	ns	ns	38

+ Each value is the average of 9 electrode readings.
‡ Hours after irrigation.
§ Matrix potential (cbar) at the time of reading the 101 hour values.
¶ Based on 10% F-test due to high variability of ODR readings.

TURFGRASS GROWTH, WATER USE, AND SOIL AERATION STATUS UNDER IRRIGATION AND SOIL COMPACTION REGIMES

by

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Soil compaction is a serious problem on recreation turfgrass sites. Two studies examined the effects of soil compaction on turfgrass growth, water use, and aeration status.

In a field study on 'Baron' Kentucky bluegrass (*Poa pratensis* L.) two compaction (none, heavy) and two irrigation (scheduled by tensiometer, set schedule) treatments were used. Soil compaction resulted in reduced shoot growth but did not influence root weight or distribution. Compaction reduced water use by 31% in the tensiometer irrigated plots compared to the uncompacted treatments. Tensiometer scheduled irrigation reduced water consumption by 27 to 50% compared to a set schedule.

In the greenhouse study 'Derby" perennial ryegrass (*Lolium perenne* L.) was subjected to compaction levels of none, moderate, and heavy. With increasing compaction, shoot and root growth declined. Water utilization at moderate and heavy compaction were 21 and 49%, respectively, of the non-compacted. Increasing compaction markedly reduced oxygen diffusion rates (ODR) with ODR levels below a critical value 53 hours after irrigation under heavy compaction.