INFLUENCE OF SOIL COMPACTION ON N UTILIZATION IN COOL SEASON TURFGRASSES

by

MELANIE SILLS

B.S., Kansas State University, 1979

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Horticulture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1981

Approved by:

Robert N. Carrow

Major Professor

TABLE OF CONTENTS

Page

List of Tables ii

Introduction 1

Literature Review 2

Soil Responses to Compaction 2

Compaction and Plant Growth 4

Soil Compaction and Nitrogen 9

Literature Cited 13

Manuscript 1 . . . Turfgrass Growth, N Use, and Water Use Under Soil Compaction and N Fertilization 20

Manuscript 2 . . . Influence of Soil Compaction on N Utilization in Tall Fescue 40

Appendix A 55

Acknowledgments 56

LIST OF TABLES

Page

Manuscript 1

Table 1. Bulk density, aeration porosity, moisture retention measurements, penetrometer resistance, and soil nitrates 34

Table 2. Visual quality, verdure, clipping yield, and total nonstructural carbohydrates (%TNC) for perennial ryegrass 36

Table 3. Evapotranspiration, water use efficiency and root weight for perennial ryegrass 37

Table 4. Percent N in leaf tissue, N-use per unit area, and percent N recovery for perennial ryegrass 38

Manuscript 2

Table 1. Bulk density, aeration porosity, moisture retention and penetrometer resistance determinations 50

Table 2. Visual quality, verdure, shoot density, clipping yield, and total nonstructural carbohydrate (%TNC) measurements for tall fescue 51

Table 3. Root weight by depth and total root weight for tall fescue 52

Table 4. Percent N in leaf tissue, N-use per unit area, percent N recovery, and soil nitrates for tall fescue 53

INTRODUCTION

Most turfgrass sites are subjected to some degree of foot or vehicular traffic. Traffic related stresses are wear and soil compaction. Wear injury occurs from physical abrasion and tearing on above ground plant parts. Compaction is the pressing together of soil particles into a more dense soil mass. Soil compaction influences soil bulk density, strength, aeration, and water relationships as well as chemical and biological properties. These parameters in turn affect all phases of crop growth. Many plant-soil-compaction interactions on various plants have been studied.

Soil compaction is the most serious turf problem on recreational sites. Management of these sites is more difficult than that on noncompacted sites. Nitrogen (N) fertilization is an important part of any management program and may be affected by compaction. However, research has been limited on N responses under compacted turf sites.

Objectives of this study were to a) determine the influence of soil compaction on N and water utilization in cool season turfgrass; b) determine the influence soil compaction plays on the N availability and utilization in water soluble or water insoluble carriers.

LITERATURE REVIEW

Soil Responses to Compaction

Soil compaction is a problem in many turf areas (44). Compaction is not the direct cause of reduced plant growth, but it adversely affects soil physical properties which in turn causes turf decline. Factors adversely influenced by compaction include bulk density, soil strength, aeration, and moisture relationships such as infiltration, percolation, and retention.

Bulk density

Bulk density increases as the soil is compacted (2, 8, 12). In recreational turf sites the increase in bulk density occurs primarily in the upper 3 cm of soil (13, 72). Many studies have been conducted where bulk density levels were varied to simulate degrees of compaction (5, 11, 27, 31, 35, 47, 55, 62, 65, 74, 80).

When using bulk density as a measure of the degree of compaction, soil texture must be considered. Compaction applied to a particular soil type must be viewed as compaction treatments relative to each other rather than as absolute degrees of compaction. A particular density representing no compaction for one soil texture may indicate severe compaction for another soil texture (11, 49).

Soil strength

Soil strength is another important measure of compaction. Soil strength measured by penetrometer resistance is a function of bulk density and moisture content at the time of sampling (14, 15, 28, 74). McCormack (47) found that soil moisture content, bulk density, and clay content influence soil strength most. Studies conducted by Gupta (28) show that soil strength increases as soil moisture tension decreases at the same bulk density. Strength is a mechanical impedance to rooting and root growth decreases as soil strength increases (26, 27, 31, 55, 57, 62, 65, 67, 74, 78).

Aeration

Compaction reduces aeration by decreasing total porosity and percent macropores while increasing percent micropores (2, 12, 30, 51, 52). The water-air-soil relationships are altered as aeration is reduced (25). Aeration is more limiting on heavier soils because the degree of compaction is dependent upon structure and texture of the soil. Compaction appears to decrease both non-capillary (air-filled at field capacity) and capillary porosity in sandy soils, whereas compaction often increases capillary porosity at the expense of non-capillary porosity in clay soils (30).

Water

Soil water status is altered by compaction. This is due to a reduction of macropores and an increased number of micropores. Moisture retention is increased (76), while water infiltration and percolation are decreased (2, 16, 18, 30, 49, 52, 64, 77, 78). Canaway (12) determined that infiltration rate for a compacted soil was only five percent of that for an uncompacted soil.

Toplayer compaction can cause a perched water table. Water does not readily cross the compacted/non-compacted boundary because the soil adhesion and cohesion forces in the top layer are too high to permit water to move into the larger voids of the lower layer (76). Reduced infiltration, which allows standing water, will increase evaporation losses since the water is not held in capillary pores. The reduction in infiltration can also lead to dry spots and runoff. Patterson and others found that increased compaction will increase runoff and erosion (49, 54, 80).

The matric potential is the attraction of the solid matrix for water (32) and is a major contributing factor influencing penetrometer resistance (31). A lower matric potential will supply fewer molecules of water for lubrication of soil particles so that at a constant bulk density soil strength increases as matric potential decreases (28).

The degree of compaction at a particular applied pressure is influenced by the percent of water in the soil during compaction. When soils are sufficiently moist, particles slide over each other and move into large pore spaces (49). The large pores are then reduced to capillary pores. However, if the pores are filled with water the shifting particles have nowhere to move, thus compaction is less severe (32). Emerson (18) defined field capacity as the maximum effective water content necessary to obtain the highest compaction level. Others have also reported maximum compaction at field capacity (30, 42).

Compaction and Plant Growth

Compaction influences soil physical properties, which may result in decreased plant growth and vigor (7). Reduced root activity from one or more of these factors often occurs, which eventually leads to reduced top growth.

Soil strength and bulk density

Soil compaction causes increased soil strength and bulk density. A soil with high soil strength and density can inhibit root penetration, which may be exhibited by altered depth, density, branching, and weight of the root mass. Also, the morphology of individual roots can be altered.

Strandberg (62) found that soil strength and not density had the primary negative effect on root growth due to mechanical impedance. If aeration is sufficient, each soil exhibits a critical soil strength beyond which rooting is restricted. However, if soil oxygen levels are deficient the critical point occurs at a lower soil strength. Therefore, mechanical impedance is affected by both soil strength and oxygen levels.

A reduced rooting depth often accompanied by increased lateral growth is common. This reduces the soil volume from which the plant can take up water and nutrients (3, 26, 27, 28, 31, 55, 62, 68, 74, 79). Phillips and Kirkham (55) found that a large percentage of roots in a 60 cm sample, taken directly under a compacted corn hill, were in the surface 10 cm of the soil. Although reduced rooting as a result of physical impedance is said to reduce nutrient uptake, Flocker (21) stated that nutrients absorbed were independent of soil density but were negatively correlated to increased soil moisture retention.

An increase in root diameter has been observed under compaction (35, 65, 67). Taylor (67) also noted a reduced root elongation rate at higher soil resistance levels. Despite the increase in lateral growth and individual root thickening, the reduced rooting depth lowered the total dry matter of roots. Cordukes (16) found this to be true in several lawn mixtures and Thurman (68) observed this on 'Tifgreen' bermudagrass. Carrow (13) found reduced root weight at both 0 to 10, and 10 to 20 cm depths for Kentucky bluegrass, perennial ryegrass, and tall fescue.

Mechanical impedance effects on elongating roots can cause morphological changes. These changes include hindrance to multiplication of cortical cells, more ruptured epidermal cells with a wavy rather than smooth surface, a generally deformed appearance, and a large percentage of the root volume is cell wall (5, 6, 62, 74).

Aeration

Soil compaction results in decreased aeration. A decline in percent of macropores reduces the soil aeration porosity. The ability of a root to grow by adding new cell wall material and to take up certain nutrients depends on energy from plant respiration (71). Root viability may decline due to insufficient oxygen (65) or supraoptimal CO_2 concentrations for respiration.

Rooting may be impeded by reduced aeration conditions and become shallow because of less oxygen at lower soil depths (3, 11, 29). Roots require pore spaces to grow through. When these are not readily available, root tips push soil particles ahead and to the side which further reduces the number of oxygen channels (71). Oxygen diffuses into the root under well aerated soil conditions but diffuses out under flooded conditions (43). Letey et al. (40) showed that reduced rooting depth is due to decreased oxygen concentrations at the deeper soil levels. They found that deep root growth in soil with adequate oxygen is possible when the portion of the root system above it is sparse due to inadequate oxygen levels.

In association with reduced aeration is reduced gas exchange which can result in a toxicity of plant exudates such as CO_2 (71) and ethylene (24). Ethylene production increases when plant tissues encounter a mechanical barrier or in anaerobic situations (22, 33). Toxic products of the soil may exist naturally at low oxygen levels. For example, plant available Fe and Mn may reach toxic levels at a low oxygen level and phytotoxic hydrogen sulfide is produced when sulfur compounds are reduced (53).

A measure of the soil aeration status is oxygen diffusion rate (ODR). An ODR of 40×10^{-8} g cm^{-2} min^{-1} is adequate for root growth while an ODR of 15×10^{-8} g cm^{-2} min^{-1} is limiting for most plants (37, 38) and ODR $<20 \times 10^{-8}$ g cm^{-2} min^{-1} for turfgrass is limiting (39, 41).

Root morphological changes due to reduced aeration include increased root porosities and short, thick adventitious roots without root hairs. Grable (24) concluded that soil aeration affects auxin since deficient aeration causes epinasty, initiation of adventitious roots, premature abscission of reproductive structures, and loss of geotropism. Slower growing roots have a shorter unsuberized zone so water uptake is reduced (36, 52). The reduced water uptake caused a reduction in root hydration in the root areas with inadequate oxygen (40).

Limited rooting results in reduced nutrient uptake (38). The problem of limited rooting in a confined volume of soil is compounded by insufficient oxygen for respiration which will reduce the amount of water and nutrients taken up by the roots. Studies by Letey et al. (37) found a reduction in nutrient accumulation, while N concentration increased with higher oxygen content (39). Waddington (75) noted that in general nutrient accumulation was not appreciably lower at low ODR. Reduced nutrient uptake may eventually affect top growth of the plant.

Reduced aeration results in reduced plant top growth (71). Growth of Kentucky bluegrass was greatly reduced at ODR of 5 to 9×10^{-8} g cm^{-2} min^{-1} (75). The limiting ODR level varies with species, age, and degree of hydration (24). Also, plants will wilt from poor aeration and from decreased soil water uptake, which reduces shoot turgidity.

Yield reduction in corn may be due to decreased oxygen in the soil rather than mechanical impedance (55) and ODR is the single most important factor correlated with potential yield of potatoes (r = +0.82) while there was no significant correlation of bulk density and yield or penetrometer resistance and yield (58).

In general, plant growth increases with increasing soil oxygen levels (36). It was found that there were 230 more miles of turfgrass roots under 5,000 ft^2 of aerated compacted soil as compared to non-aerated compacted soil (29).

Water

Soil compaction results in decreased percentage of large soil pores which hinders drainage of water. The altered soil moisture conditions will affect plant responses such as root length and weight, and the decreased water use and nutrient uptake will eventually reduce top growth and yield.

Compaction has been found to reduce water uptake (51) but Harper (29) found that water and aeration treatments had a greater influence on turf quality than compaction. This suggests that mechanical impedance is not the major factor influencing turfgrass growth on compacted soils (29).

The decreased drainage of compacted soils leaves a greater amount of water in the soil for a longer period of time (16). Increased water content results in shallow roots (29). Skirde (61) noted that improved drainage of a compact subsoil improved turfgrass looks and increased drought resistance by promoting deeper rooting.

A decline in water use can occur with a decrease in oxygen (40). One reason for this may be that water permeability of root cells decreases with low oxygen levels (52). Also, Letey (36) found that with slower growth of roots in compacted soils fewer young root areas occur and water uptake is reduced since permeability decreases with age. However, water use per unit dry weight is less under compacted conditions (40).

There is a decrease in water translocation within plants growing under low soil oxygen conditions due to a reduction in root hydration and number of roots (40). The water content of roots is important because osmotic potential within the elongating root cells create the pressure potential necessary for root growth (66). Reduced oxygen levels within the root may result in reduced shoot turgidity (40) but the stress of compaction can also cause limited water vapor loss by stomatal closure (52). However, stomatal closure will decrease air flow into leaf tissue.

Reduced water infiltration may leave compacted soils dryer after a short heavy rain or irrigation. The increase in matric suction in dry soil is a major factor limiting root elongation and contributing to increased penetrometer resistance (31). Taylor (67) found that roots elongate fastest at low resistance, root length was more affected than root volume or weight, and that root diameter increased as soil water content increased, especially at a low soil strength.

Altered soil moisture conditions have a detrimental effect on shoot growth and yield as well as roots. Carrow (13) found that shoot density, verdure, percent turf cover, and visual quality were reduced in various degrees in three species of turfgrass under compaction. The greatest decrease in growth of tops of maize occurred with dry moisture regimes and a bulk density of 1.57 g/cc or more (28). Anaya (4) found a high correlation ($r = 0.94$) between water consumption and grain production in wheat.

Soil Compaction and Nitrogen

Plants absorb most of their N in the NH_4^+ and NO_3^- forms. The quantity of these two ions depends on the amounts supplied as commercial N fertilizer and released from soil organic reserves. Quantities released from organic reserves depends on such factors as N-mineralization, N-immobilization, and losses from the soil (69).

Nelson (51) found that compaction restricted nutrient uptake due to a combination of adverse factors such as lack of oxygen, increased CO_2, poor water utilization, and root impedance. Higher N rates on a non-compacted soil increased yield and N concentration of 'Midland' Bermudagrass, while the percent recovery of applied N decreased (45). Gore (23) found that additional N improved turfgrass cover in the absence of compaction whereas it was actually detrimental in the presence of compaction.

Bulk density

The bulk density for a particular soil texture gives information as to the porosity of the soil. An increased bulk density will have a lower total porosity and percentage of macropores. This reduces water flow and thus N diffusion. Gupta (28) has stated that in a compacted soil, bulk density not amount of nutrient, is limiting for nutrient uptake.

Nitrogen concentration expressed as percent on a dry basis increased with increased bulk densities in maize (28) and tomatoes (21). However, the total amount of nutrients absorbed was independent of density (1.2 - 1.6 g/cc) when soil moisture was held at 0.7 bar. In sandy loam soil, N uptake increased with bulk densities to 1.3 g/cc and declined beyond 1.4 g/cc. In loamy sand, N uptake increased with bulk densities to 1.5 g/cc and decreased sharply beyond 1.6 g/cc (63).

A bulk density increase may produce a high protein, low sugar plant (20). Dunn (17) found that this high protein or N content in bermudagrass was associated with reduced cold-hardiness.

Aeration

Nutrient uptake, especially anions, require energy from respiration. Deficient oxygen conditions reduce the efficiency of fertilizer use due to restricted root growth and reduced plant respiration.

Deficient soil oxygen also allows the N to transform into unusable or unstable compounds. N mineralization is the conversion of organic N to a mineral form (NH_4^+, NO_3^-, or NO_2^-). N mineralization was reduced by slight compaction (34). Some of the NH_4^+ released may be converted by nitrification to NO_3^--N by Nitrobacteria in two oxygen dependent steps. Maximum nitrification occurs at 20% oxygen. Microorganisms produced only half as much NO_3^- at 2.1 percent oxygen as compared to 20 percent oxygen (34). Denitrification is the biochemical reduction of nitrates under anaerobic conditions where N_2O and N_2 are released as gases (69).

Compaction reduces oxygen in flooded soils. As a result, NO_3^- is unstable and reduced to NH_4^+, NO_2^-, N_2O, and N_2 by NO_3^- respiration or to NH_3^+ by NO_3^- assimilation in anaerobic soil. Common denitrification occurs in intermediate levels of soil oxygen and NO_3^- is usually reduced to N_2. These reactions decrease the N in the soil by gaseous escape (10, 52).

Nutrient uptake is reduced in low oxygen conditions due to reduced root growth and N losses (38, 52). However, Waddington (75) found that plant nutrient accumulation was not appreciably decreased at low ODR (<5 to 9×10^{-8} g cm^{-2} min^{-1}) for three species of grass. Others have reported a decline in N concentration with decreasing oxygen levels (39, 40).

Water

Compaction affects mass flow and diffusion, which are two methods for movement of nutrients to plant roots. For NO_3^- mass flow is significant (53). A reduction in soil moisture reduces both water and NO_3^- ion movement.

As soil moisture is reduced, water movement decreases and thus the water movement to the root surface is reduced. The moisture films around the soil particles are thinner and diffusion of ions through these films is restricted.

Delivery of nutrients to root surfaces is probably most rapid at field capacity (69). To prevent further loss of the NO_3^- ion, Brown found that when irrigation rates were kept near or below evapotranspiration rates leachate ions from plots fertilized with soluble sources were minimized (9). The influence of an N fertilizer will vary with the moisture in the soil (19). For example, the release of N from a slow release fertilizer such as isobutyldiurea and sulfur coated urea is dependent upon the amount of water in the soil.

Plant growth is affected by water-fertilizer relationships. Flocker (21) found a negative correlation between nutrients absorbed and increased soil moisture tension. Plants grown at higher tension had greater concentrations of nutrients absorbed except B and P. Singh et al. (60) found that increased N applications with increasing irrigations on wheat (from one to three 7.5 cm irrigations) increased the N uptake.

LITERATURE CITED

1. Aceves-N. E., L. H. Stolzy, and G. R. Mehuys. 1975. Response of three semi-dwarf Mexican wheats to different aeration conditions in the rooting medium at a constant salinity level. Soil Sci. Soc. Am. Proc. 39:515-518.

2. Aljibury, F. K. 1967. Turf and soil water-air relationship. Calif. Turfgrass Culture 17(3):19.

3. ____________, J. L. Meyer, and W. E. Wildman. 1977. Managing compacted and layered soils. Leaflet 2635. Berkeley: Div. of Agric. Sci., Univ. of Calif.

4. Anaya, M. G., and L. H. Stolzy. 1972. Wheat response to different soil water-aeration conditions. Soil Sci. Soc. Am. Proc. 36:485-489.

5. Baligar, V. C., V. E. Nash, M. L. Hare, and J. A. Price, Jr. 1975. Soybean root anatomy as influenced by soil bulk density. Agron. J. 67:842-844.

6. Barley, K. P., and E. L. Greacen. 1967. Mechanical resistance as a soil factor influencing the growth of roots and underground shoots. Adv. in Agron. 19:1-43.

7. Barnes, K. K., W. M. Carleton, H. M. Taylor, R. I. Throckmorton, and G. F. Vandenberg (ed.). 1971. Compaction of agricultural soils. Am. Soc. of Agric. Eng., St. Joseph, Mich.

8. Beard, James B. 1973. Turfgrass: science and culture. Prentice-Hall, Inc., Englewood Cliffs, N. J.

9. Brown, K. W., R. L. Duble, and J. C. Thomas. 1977. Influence of management and season on fate of N applied to golf greens. Agron. J. 69:667-671.

10. Buresh, R. J., and W. H. Patrick, Jr. 1978. Nitrate reduction to ammonium in anaerobic soil. Soil Sci. Soc. Am. J. 42:913-918.

11. Camp, C. R., and Z. F. Lund. 1964. Effect of soil compaction on cotton roots. Crops and Soils 17:13-14.

12. Canaway, P. M. 1978. Trials of turfgrass wear tolerance and associated factors - a summary of progress 1975-1977. J. Sports Turf Res. Inst. 54:7-14.

13. Carrow, R. N. 1980. Influence of soil compaction on three turfgrass species. Agron. J. 72:1038-1042.

14. Chancellor, W. J. 1971. Compaction as it affects soil conditions. Effects of compaction on soil strength. In K. K. Barnes, W. M. Carleton, H. M. Taylor, R. I. Throckmorton, and G. F. Vandenberg (ed.) Compaction of agricultural soils. Am. Soc. Agric. Eng., St. Joseph, Mich.

15. ___________. 1977. Compaction of soil by agricultural equipment. Bulletin 1881. Berkeley: Div. of Agric. Sci., Univ. of Calif.

16. Cordukes, W. E. 1968. Compaction. The Golf Super 36(8):20-24.

17. Dunn, J. H., and C. J. Nelson. 1974. Chemical changes occurring in three bermudagrass turf cultivars in relation to cold hardiness. Agron. J. 66:28-31.

18. Emerson, W. W. 1978. Aggregate classification and the hydraulic conductivity of compacted subsoils. In W. W. Emerson, R. D. Bond, and A. R. Dexter (ed.) Modification of Soil Structure. John Wiley and Sons, New York, N. Y.

19. Engel, R. E. 1974. Influence of nitrogen fertilization on species dominance in turfgrass mixtures. Proc. of the Second Int. Turf Res. Conf. p. 104-111.

20. Flocker, W. J., and R. C. Menary. 1960. Some physiological responses in two tomato varieties associated with levels of bulk density. Hilgardia 30:101-121.

21. ___________, and D. R. Nielsen. 1962. The absorption of nutrient elements by tomatoes associated with levels of bulk density. Soil Sci. Soc. Am. Proc. 26:183-186.

22. Goeschl, J. D., L. Rappaport, and H. K. Pratt. 1966. Ethylene as a factor regulating the growth of pea epicotyls subjected to physical stress. Plant Physiology 41:877-884.

23. Gore, A. J. P., R. Cox, and T. M. Davies. 1979. Wear tolerance of turfgrass mixtures. J. Sports Turf Res. Inst. 55:45-68.

24. Grable, A. R. 1966. Soil aeration and plant growth. Adv. in Agron. 18:57-106.

25. ___________. 1971. Compaction as it affects soil conditions. Effects of compaction on content and transmission of air in soils. In K. K. Barnes, W. M. Carleton, H. M. Taylor, R. I. Throckmorton, and G. F. Vandenberg (ed.) Compaction of agricultural soils. Am. Soc. Agric. Eng., St. Joseph, Mich.

26. Grimes, D. W., R. J. Miller, and P. L. Wiley. 1975. Cotton and corn root development in two field soils of different strength characteristics. Agron. J. 67:519-523.

27. ___________, W. R. Sheesley, and P. L. Wiley. 1978. Alfalfa root development and shoot regrowth in compact soil of wheel traffic patterns. Agron. J. 70:955-958.

28. Gupta, J. P., and I. P. Abrol. 1970. A study of the effect of soil compaction and moisture regimes on the growth and chemical composition of maize plants. Indian Soc. Soil Sci. J. 18(4):397-403.

29. Harper, J. 1953. Irrigation, compaction, and aeration of fairway turf. USGA J. and Turf Mgmt. 6(4):27-31.

30. ___________. 1955. Turfgrasses and compaction. Univ. of Florida Turfgrass Conf. Proc. 3:101-103.

31. Hemsath, D. L., and A. P. Mazurak. 1974. Seedling growth of sorghum in clay-sand mixtures at various compactions and water contents. Soil Sci. Soc. Am. Proc. 38:387-390.

32. Hillel, D. 1971. Soil and water: physical principles and processes. Academic Press, New York, N. Y.

33. Kays, S. J., C. W. Nicklow, and D. H. Simons. 1974. Ethylene in relation to the response of roots to physical impedance. Plant and Soil 40:565-571.

34. Kemper, W. D., B. A. Stewart, and L. K. Porter. 1971. Compaction as it affects soil conditions. Effects of compaction on soil nutrient status. In K. K. Barnes, W. M. Carleton, H. M. Taylor, R. I. Throckmorton, and G. F. Vandenberg (ed.) Compaction of agricultural soils. Am. Soc. Agric. Eng., St. Joseph, Mich.

35. Kulkarni, B. K., and N. K. Savant. 1977. Effect of soil compaction on root-cation exchange capacity of field and horticultural crop plants. Plant and Soil 48(2):269-278.

36. Letey, J., O. R. Lunt, L. H. Stolzy, and T. E. Szuszkiewicz. 1961. Plant growth, water use and nutritional response to rhigosphere differentials of oxygen concentration. Soil Sci. Soc. Am. Proc. 25:183-186.

37. ___________, L. H. Stolzy, N. Valoras, and T. E. Szuszkiewicz. 1962. Influence of soil oxygen on growth and mineral concentration of barley. Agron. J. 54:538-540.

38. ______________________, T. E. Szuszkiewicz, and N. Valoras. 1962. Soil aeration - essential for maximum plant growth. Calif. Agric. 16(3):6-7.

39. ______________________, O. R. Lunt, and V. B. Youngner. 1964. Growth and nutrient uptake of Newport bluegrass as affected by soil oxygen. Plant and Soil 20(2):143-148.

40. ___________, W. F. Richardson, and N. Valoras. 1965. Barley growth, water use, and mineral composition as influenced by oxygen exclusion from specific regions of the root system. Agron. J. 57:629-631.

41. ___________, W. C. Morgan, S. T. Richards, and N. Valoras. 1966. Physical soil amendments, soil compaction, irrigation, and wetting agents in turfgrass management. III. Effects on oxygen diffusion rates and root growth. Agron. J. 58:531-535.

42. Lunt, O. R. 1961. Grass roots and soil compaction. Northern Calif. Turfgrass Inst. Proc. p. 10-11.

43. Luxmoore, R. J., and L. H. Stolzy. 1972. Oxygen consumption rates predicted from respiration, permeability and porosity measurements on excised wheat root segments. Crop. Sci. 12:442-445.

44. Madison, J. H. 1971. Principles of turfgrass culture. Van Nostrand Reinhold Co., N. Y.

45. Mathias, E. L., O. L. Bennett, and P. E. Lundberg. 1978. Fertilization effects on yield and N concentration of Midland bermudagrass. Agron. J. 70:973-976.

46. McAfee, J. A. 1976. Fertilizing economically. Weeds, Trees and Turf. 15(4):36-38.

47. McCormack, D. E., and L. P. Wilding. 1979. Soil properties influencing strength of Canfield and Geeburg soils. Soil Sci. Soc. Am. J. 43:167-173.

48. Mitchell, H. L. 1972. Microdetermination of nitrogen in plant tissues. J. Assoc. Offic. Anal. Chemists 1:55.

49. Morgan, W. C., J. L. Letey, S. J. Richards, and N. Valoras. 1966. Physical soil amendments, soil compaction, irrigation, and wetting agents in turfgrass management. I. Effects on compactability, water infiltration rates, evapotranspiration, and number of irrigations. Agron. J. 58:525-528.

50. Morris, D. L. 1948. Quantitative determination of carbohydrates with Dreywood's anthrone reagent. Science 107:254-255.

51. Nelson, W. E., G. S. Rahi, and L. Z. Reeves. 1975. Yield potential of soybean as related to soil compaction induced by farm traffic. Agron. J. 67:769-772.

52. Nelson, W. L. 1976. Soil compaction puts crops under great stress. Agron. J. 54:29-34.

53. Parish, D. H. 1971. Soil conditions as they affect plant establishment, root development, and yield. Effects of compaction on nutrient supply to plants. In K. K. Barnes, W. M. Carleton, H. M. Taylor, R. I. Throckmorton, and G. F. Vandenberg (ed.) Compaction of agricultural soils. Am. Soc. Agric. Eng., St. Joseph, Mich.

54. Patterson, J. C. 1977. Soil compaction - effects on urban vegetation. J. of Arboriculture 3(9):161-167.

55. Phillips, R. E., and D. Kirkham. 1962. Soil compaction in the field and corn growth. Agron. J. 54:29-34.

56. Rimmer, D. L. 1979. Effects of increasing compaction on grass growth in colliery spoil. J. Sports Turf Res. Inst. 55:153-162.

57. Rosenberg, N. J. 1964. Response of plants to the physical effects of soil compaction. Adv. in Agron. 16:181-196.

58. Saini, G. R. 1976. Relationship between potato yield and oxygen diffusion rate of subsoil. Agron. J. 68:823-825.

59. Shearman, R. C., and J. B. Beard. 1975. Turfgrass wear tolerance mechanisms: I. Wear tolerance of seven turfgrass species and quantitative methods for determining turfgrass wear injury. Agron. J. 67:208-211.

60. Singh, N. T., A. C. Vig, R. Singh, and M. R. Chaudhary. 1979. Influence of different levels of irrigation and nitrogen on yield and nutrient uptake by wheat. Agron. J. 71:401-404.

61. Skirde, W. 1974. Soil modification for athletic fields. Proc. of the Second Int. Turf Res. Conf. p. 261-269.

62. Strandberg, J. O., and J. M. White. 1979. Effect of soil compaction on carrot roots. J. Am. Soc. Hort. Sci. 104(3):344-349.

63. Subramanian, S. 1973. Effect of soil compaction on plant growth. Farm Fact 7(10):3-4.

64. Swartz, W. E., and L. T. Kardos. 1961. Effects of compaction on physical properties of sand-soil-peat mixtures at various moisture contents. Agron. J. 53:7-10.

65. Taylor, H. M., M. G. Huck, and B. Klepper. 1972. Root development in relation to soil physical conditions. In D. Hillel (ed.) Optimizing the soil physical environment toward greater crop yields. pp. 57-77. Academic Press, New York, N. Y.

66. ___________, and L. F. Ratliff. 1969. Root growth pressures of cotton, peas, and peanuts. Agron. J. 61:398-402.

67. ________________________. 1969. Root elongation rates of cotton and peanuts as a function of soil strength and soil water content. Soil Sci. 108(2):113-119.

68. Thurman, P. C., and F. A. Pokorny. 1969. The relationship of several amended soils and compaction rates on vegetative growth, root development and cold resistance of Tifgreen bermudagrass. J. Am. Soc. Hort. Sci. 94:463-465.

69. Tisdale, S. L., and W. L. Nelson. 1975. Soil fertility and fertilizers. Third Ed. MacMillan Publ. Co., Inc., New York, N. Y.

70. Trouse, A. C., Jr. 1971. Soil conditions as they affect plant establishment, root development, and yield. Effects of soil moisture on plant activities. In K. K. Barnes, W. M. Carleton, H. M. Taylor, R. I. Throckmorton, and G. F. Vandenberg (ed.) Compaction of agricultural soils. Am. Soc. Agric. Eng., St. Joseph, Mich.

71. ___________. 1971. Soil conditions as they affect plant establishment, root development, and yield. Effects of soil aeration on plant activities. In K. K. Barnes, W. M. Carleton, H. M. Taylor, R. I. Throckmorton, and G. F. Vandenberg (ed.) Compaction of agricultural soils. Am. Soc. Agric. Eng., St. Joseph, Mich.

72. Van Wijk, A. L. M., W. B. Verhaegh, and J. Beuving. 1977. Grass sportsfields: toplayer compaction and soil aeration. Rasen-Turf-Gazon 8:47-52.

73. Valoras, N., W. C. Morgan, and J. Letey. 1966. Physical soil amendments, soil compaction, irrigation, and wetting agents in turfgrass management II. Effects on top growth, salinity, and minerals in the tissue. Agron. J. 58:528-531.

74. Voorhees, W. B., D. A. Farrell, and W. E. Larson. 1975. Soil strength and aeration effects on root elongation. Soil Sci. Soc. Am. Proc. 39:948-953.

75. Waddington, D. V., and J. H. Baker. 1965. Influence of soil aeration on the growth and chemical composition of three grass species. Agron. J. 57:253-258.

76. Warkentin, B. P. 1971. Compaction as it affects soil conditions. Effects of compaction on content and transmission of water in soils. In K. K. Barnes, W. M. Carleton, H. M. Taylor, R. I. Throckmorton, and G. F. Vandenberg (ed.) Compaction of agricultural soils. Am. Soc. Agric. Eng., St. Joseph, Mich.

77. Watson, J. R. 1967. Water requirements as a function of clipping height and frequency. Calif. Turfgrass Culture 17(1):1-3.

78. Wildman, W. E., and K. D. Gowans. 1975. Soil physical environment and how it affects plant growth. Leaflet 2280. Berkeley: Div. of Agric. Sci., Univ. of Calif.

79. Wilkinson, J. F., and D. T. Duff. 1972. Rooting of *Poa annua* L., *P. pratensis* L., and *Agrostis palustris* Huds. at three soil bulk densities. Agron. J. 64:66-68.

80. Zimmerman, T. L., D. V. Waddington, and J. M. Duich. 1971. Effect of amendment, compaction, soil depth, and time on the physical properties of soil mixtures. Agron. Abstr. 63:52.

MANUSCRIPTS

These manuscripts are written in the style of and for publication in Agronomy Journal.

Turfgrass Growth, N Use, and Water Use Under Soil Compaction and N Fertilization

M. J. Sills and R. N. Carrow

ABSTRACT

Soil compaction is a problem in many turf areas. In this greenhouse study the influence of soil compaction on morphological and physiological aspects of Lolium perenne L. 'Pennfine' was investigated. The turfgrass was subjected to two compaction treatments with an 11.5 kg falling weight: a) 0x - none, b) 20x - weight was dropped 20 times from a height of 36.8 cm. Fertilization rate treatments were 0.5 and 1.0 kg N/100 m^2. Nitrogen-carrier treatments were water soluble N applied as NH_4NO_3 and water insoluble applied as IBDU. Two parts fine, montmorillonitic mesic Aquic Arguidoll soil was used to one part sand.

Increasing compaction increased bulk density, water retention, and soil strength while decreasing aeration porosity. Visual quality, clipping yield, N-use efficiency, evapotranspiration, and root growth declined as compaction increased. Verdure, total nonstructural carbohydrates (TNC), and percent N in leaf tissue were not affected by compaction. Initial TNC levels, total water use efficiency, and total N-use efficiency increased as N-rate increased. Clipping yield, N-use efficiency, and water use efficiency were higher with a water soluble N-carrier. TNC at day 72, percent N in leaf tissue early in the study, and root weight in the surface 5 cm increased with water insoluble fertilizer. The most detrimental effect of compaction was on root weight at a high water soluble N application. Thus, compaction not only affected turf growth but it also influenced plant and soil responses to different N-rates and N-carriers as well as plant-water relations.

Additional index words: Lolium perenne L., N-use efficiency, Aeration porosity, Clipping yield, Soil strength, Perennial ryegrass.

Most turfgrass sites are subjected to some degree of foot or vehicular traffic. Traffic related stresses are wear and soil compaction. Wear injury occurs from physical abrasion and tearing on above ground plant parts (3). Compaction influences soil bulk density, strength, aeration, and water relationships, which in turn affect plant growth.

Madison (17) noted that soil compaction was the most serious turf problem on recreational sites. Turfgrass responses to compaction are often confounded by wear effects (7, 12). Shearman and Beard (25) investigated wear tolerance without including compaction effects.

In most studies turf root growth was observed to decline with increasing compaction (9, 16, 23, 26); however, increased growth (31) and no response (30) have been observed. Valoras (28) found that compaction reduced root growth in bermudagrass. Conflicting growth responses can often be explained in terms of the soil texture and degree of compaction. For example, moderate compaction on a loamy sand may improve moisture relations for rooting. Reduced shoot growth due to compaction as exhibited by decreased plant density, visual quality, and verdure have been reported (8, 26).

Nitrogen relations may be affected by soil compaction. Increased N-rate enhanced turfgrass yield (17) and percent N in leaf tissue under non-compacted conditions (24). Excess N resulted in decreased rooting when individual plants were in competition. After reviewing the results of many investigators, Madison (17) concluded that adverse effects of compaction could not be compensated for by fertilizer or water. Literature concerning soil compaction and the effects of various N-rates or N-carriers on turfgrass is limited.

Compaction may also influence water use (16). Letey (16) found that the slower growth of roots in compacted soil resulted in fewer young root areas. Also, root permeability decreased due to root maturation which reduced water uptake. Increased water content of compacted soils may contribute to shallow rooting as observed by Gore et al. (12).

The objective of this study was to determine the influence of soil compaction on nitrogen and water utilization in perennial ryegrass from water soluble and water insoluble N-carriers.

MATERIALS AND METHODS

This 1980 greenhouse study was established on a two part soil:one part sand mix. The soil was a Chase silt loam (fine, montmorillonitic mesic Aquic Arguidolls). *Lolium perenne* L. 'Pennfine' perennial ryegrass was seeded 31 Dec. 1979. All pots received 0.125 kg N/100 m^2 on 3 Jan. 1980 as urea 46-0-0.

Pots were constructed using 30.5 cm diam PVC pipe cut into 76.2 cm segments. A plastic plate with one drainage hole was sealed into the bottom. Pots were constructed to allow turfgrass root growth and water drainage similar to that in a field. A 5 cm layer of coarse gravel was placed at the bottom of each container which were then filled with the soil:sand mix. The soil was allowed to settle by watering frequently for three days.

Four replications per treatment in a 2 x 2 x 2 factorial, randomized complete block design were used. Each plot received one of eight treatments each having one compaction, one fertilization rate, and one N-carrier. Compaction treatments were: a) 0x - none; b) 20x - an 11.5 kg weight was dropped 20 times from a height of 36.8 cm on 16 Mar. 1980. The soil was saturated and allowed to drain 24 hours before the compaction. By bulk density determinations, it was found that compaction was restricted to the surface 3 cm. Nitrogen fertilization rate (NR) treatments were: 0.5 and 1.0 kg N/100 m^2. Nitrogen carrier (NC) treatments were: water soluble N applied as NH_4NO_3 and water insoluble applied as IBDU (coarse). All fertilizations were applied once on 29 Mar. 1980. Tensiometers were installed at 5 and 25 cm below the soil surface in three replications. These were used to monitor water use and as an aid to irrigation. Sufficient water was applied when the first tensiometer reached -0.70 to -0.80 bar to return all tensiometers to a 0 bar value.

Clippings were collected, dried at 65 C for 24 hours, weighed and analyzed for percent N in the tissue from a micro-Kjeldahl digestion (19) using a selective NH_3 ion electrode (1) (Appendix A). Verdure was determined from one sample (5.4 cm diam) per plot. Clipping samples were used to determine total nonstructural carbohydrates (TNC) by the method of Morris (20). Visual quality ratings were based on turfgrass color, density, and uniformity. A scale of (9 = ideal, 6.5 = acceptable, 1 = no live turf) was used. Root weights were determined at the end of the study by combining four cores (2.0 cm diam each) per plot for each depth, washing, drying at 65 C for 24 hours, and weighing. Soil NO_3^- was measured every two weeks from one core (2.0 cm diam) per plot. Samples were separated by depth, dried at 30 C for 24 hours, then seived to pass through a 20 mesh screen. A 10 g sample was analyzed using a selective NO_3^- ion electrode (1). Soil physical measurements were obtained in June to determine the degree of compaction. Bulk density, moisture retention, and aeration porosity determinations were made using a single core (5.4 cm diam x 3 cm) at each depth per plot. Penetrometer resistance was measured to test soil surface strength at field capacity. Tensiometers were read daily to determine the cm of water used and the water use efficiency.

RESULTS AND DISCUSSION

Soil Physical Properties

Soil physical properties were affected by compaction (Table 1). Bulk density values when averaged over N-rates and N-carriers showed an increase from 1.26 to 1.34 g/cm^3 when going from the 0x to 20x compaction treatments. Total pore space was reduced from 42.3 to 39.2%. Water retention at -0.33 bar increased 8.3%. Warkentin (29) noted that compaction increases water retention in the range where it is available to plants.

Aeration porosity at -0.10 bar moisture content decreased from 20.9 to 17.1%, or an 18.2% reduction due to compaction. Madison (17) recommended 10 to 20% non-capillary pore space after compaction for sports-turf areas. Penetrometer values increased from 0.68 to 1.09 kg/cm^2 when going from the 0x to 20x compaction. This is in agreement with Hemsath (14) who found that penetrometer resistance increased as bulk density increased. Sampling was at -0.33 bar since penetrometer resistance increases as water content decreases.

Turfgrass Growth Responses

Soil compaction is an indirect stress on turfgrass. Compaction affects properties such as soil bulk density, aeration, and moisture retention; and all influence plant growth activity. These altered physical properties are a stress and may result in plant decline.

Shoot growth. Visual quality was reduced with increased compaction regardless of N-rate or N-carrier (Table 2). At the beginning of the study, the water soluble N-carrier somewhat reduced the effects of compaction on visual quality. The soil used in this study apparently had some residual N since even the low N-rate exhibited very good quality. The decline in turf quality as compaction increased was similar to trends observed by other investigators (3, 7, 9, 12, 26, 27, 28).

While verdure was not affected by any of the treatments, clipping yield declined with increasing compaction throughout the study (Table 2). In the first 22 days of this study, the immediate availability of N from the water soluble N-carrier is evident by the greater clipping yield. The turfgrass responded to the higher N-rate treatment during the three to seven week period following fertilization, but by the eighth week plant uptake or leaching seemed to have depleted the excess N. Neither N-rate or N-carrier treatments alleviated the adverse effects of compaction on clipping yield.

Turf responses to compaction were similar to other reports. Thurman (26) and Valoras (28) reported that compaction reduced shoot growth of bermudagrass. Van Wijk et al. (27) noted that above ground growth was reduced at ODR below 10×10^{-8} g cm^{-2} min^{-1} resulting from compaction.

It is well known that turfgrasses respond to N (3, 13) but the effects of N fertilization on compacted sites are less clear. Fertilization studies are generally conducted on non-compacted turf and the results may not apply to compacted situations. Gore et al. (12) found that additional N improved turfgrass cover in the absence of compaction whereas it was actually detrimental in the presence of compaction.

Total nonstructural carbohydrates were not affected by compaction but during the first month after fertilization TNC levels increased slightly at the higher N-rate (Table 2). At 72 days after fertilization, TNC levels were influenced by N-carrier. The water insoluble N-carrier resulted in a higher TNC level for the compacted turf but only at the high N-rate. This is contradictory to Madison (17) who reported that increasing N caused excessive growth which reduced carbohydrate storage. However, clipping TNC levels were measured and not total shoot TNC.

Root weight. Compaction reduced perennial ryegrass root weight in all soil zones and total root weight by 30.6% when averaged over all treatments (Table 3). Compaction applied to the low N-rate turf caused a 13.3% reduction in rooting but at the high N-rate a 44.6% decrease occurred. The restricted rooting was particularly evident under the high N-rate plus the water soluble carrier with a 53% reduction for the compacted versus non-compacted turf. Deep root growth in the 15-25 cm zone was least for the compacted plus high N plus water soluble carrier combination.

Perennial ryegrass rooting was least affected by compaction in a study comparing three cool season turfgrasses (8). Thus, these rooting trends may be even more evident for other turf species.

The results of this study suggest that excess N coupled with compaction has a detrimental synergistic effect on rooting. Madison (17) noted that when N levels are adequate to bring individual plants into competition, increased N resulted in decreased rooting. Other researchers have reported reduced turfgrass rooting under compaction (2, 9, 16, 23, 26), but they did not include N-rate or N-carrier responses.

Water Use

Evapotranspiration (ET). Compaction reduced evapotranspiration from 51.5 to 37.1 cm H_2O over the period of the study when averaged over N-rate and carrier (Table 3). N-rate and N-carrier had little influence on ET except in the high N-rate treatment during the last period of the study, where ET was reduced by compaction more than under low N-rate.

Reduced evapotranspiration leaves a greater amount of water in the soil for a longer period of time. Letey (15) found that the slower growth of roots in compacted soils results in fewer young root areas. Also, root permeability decreased due to root maturation which reduced water uptake. Increased soil water content produced shallow rooting in a study by Gore et al. (12). Since water consumption is reduced under compaction, care should be taken not to irrigate such sites except when needed in order to avoid excessive soil moisture levels.

Water use efficiency. Water use efficiency (liters of H_2O used per g dry weight tissue produced) was not affected by compaction (Table 3). The water soluble N-carrier exhibited more efficient water use than the water insoluble N-carrier during the first 22 days of the study (Table 3). During this period, the immediate N availability of water soluble fertilizer increased clipping yields and made more efficient use of applied water. High N-rate treatments tended to be more water use efficient than low N-rates during the middle of the study. This was also a period when high N-rate treatments produced higher clipping yields. Burton et al. (6) found that a high N rate was 20% more water use efficient in common bermudagrass.

Under the conditions of this investigation N-rate and N-carrier treatments had a greater influence on water use efficiency than compaction. However, compaction affected evapotranspiration more than N treatments.

Nitrogen Responses

Plant nitrogen. Leaf tissue N content was not affected by compaction or N-rate but N-carrier responses were noted early in the study. The immediate availability of N in the water soluble fertilizer treatments produced leaf tissue with a higher percent N during the initial two weeks of the study (Table 4). Roberts (24) reported N-rate influenced percent N in leaf tissue with 2.8% N for low fertility grass, 3.5% N for moderate fertility grass, and 4.4 to 4.9% N for grass receiving excessive N. Values in this study were in the fertile range. Nitrogen concentrations were found to increase with increased soil bulk density in maize (13) and tomatoes (10). Letey et al. (15) noted that N concentration increased with increased oxygen levels that may occur at higher bulk densities (7).

While compaction did not influence percent N in leaf tissue, it did reduce N-use efficiency by 32.2% averaged over N treatments (Table 4). Slower shoot growth of compacted plots reduced the total N taken into the plants per unit area and the limited root growth reduced the volume of soil from which N could be obtained. Additional N increased N-use per unit area but this was inefficient, since a 100% increase in applied N increased N-use per unit area only 10%, averaged over compaction and N-carrier treatments. A water soluble N-carrier increased N-use per unit area by 11.5%. Compaction reduced N-use per unit area regardless of N-carrier but the reduction was 39.5% for the water solubel N-carrier while only 23.1% for the water insoluble N-carrier. Madison (17) noted that each added increment of a mineral increases yield, but the increase is smaller with each added increment. Higher N-rates on a non-compacted soil increased yield and N concentration of 'Midland' bermudagrass, while the percent recovery of applied N decreased (18).

Compaction, high N-rate, and water insoluble N-carrier reduced N recovery (Table 4). Compaction reduced percent N recovery by 32.1%. A high N-rate was only 55% as efficient in N recovery as the low N-rate and the water insoluble N-carrier was only 89% as efficient in N recovery as the water soluble N-carrier. Percent N recovery values were greater than 100% due to the turf extracting more N than was applied. The soil used had a high N fertility. Goetze (11) found efficiency of N recovery for ryegrass was about 30% for soluble sources, about 25% for organic residues, and less than 20% from UF nitrogen.

Soil nitrates. Nitrates were reduced by compaction at 12 days after fertilization in the upper 5 cm of soil, possibly by gaseous loss (Table 1). Aeration decreased with compaction and Buresh (5) noted that with anaerobic conditions soils lose NO_3^- by NO_3^- respiration or NO_3^- assimilation. Beyond 12 days after fertilization compaction did not influence NO_3^- levels. Parish (21) states that mass flow is significant for NO_3^- transport and compaction reduces mass flow, which could result in higher initial NO_3^- levels near the soil surface.

Up to the 28 day sampling period, the water soluble N-carrier treatments had higher soil NO_3^- levels than the water insoluble carrier. Nitrogen rate had little influence on soil NO_3^- levels except for the 12 day sampling date. At that time the higher water soluble N-rate produced very high NO_3^- levels in the surface 0-5 cm zone. The NO_3^- levels in this study were low but within the range noted by Rieke and Ellis (22).

In the present study shoot growth and rooting were decreased under compaction. When high N-rate of a water soluble carrier was coupled with compaction, root growth was reduced even further. Susceptibility to drought stress could increase under these growth conditions. Plant N use efficiency was adversely affected by compaction as was percent N recovery. Also, soil NO_3^- appeared to decrease initially under compaction.

Compaction did reduce water use as measured by ET. This would appear to result from a combination of a limited root system, altered moisture release curve, slower shoot growth rate, and perhaps a less viable root system due to lower aeration. With a limited root system, less viable roots, and an altered moisture release curve, little of the water conserved under compaction (versus no compaction) would be unavailable for future use.

Compaction did not influence water use efficiency. The use of a water soluble N-carrier did increase water use efficiency by producing more shoot growth. However, this did not continue later in the study when limited rooting may have reduced water availability.

Obviously, the same N fertilization and irrigation programs on compacted versus non-compacted turf sites would produce different responses. On recreational turf, fertilization and irrigation regimes should be carefully developed to provide adequate plant growth as well as efficient N and water use.

LITERATURE CITED

1. Anonymous. 1978. Analytical methods guide. 9th ed. Orion Res., Inc., Cambridge, Mass.

2. Barley, K. P., and E. L. Greacen. 1967. Mechanical resistance as a soil factor influencing the growth of roots and underground shoots. Adv. in Agron. 19:1-43.

3. Beard, James B. 1973. Turfgrass: science and culture. Prentice-Hall, Inc., Englewood Cliffs, N. J.

4. Brown, K. W., R. L. Duble, and J. C. Thomas. 1977. Influence of management and season on fate of N applied to golf greens. Agron. J. 69:667-671.

5. Buresh, R. J., and W. H. Patrick, Jr. 1978. Nitrate reduction to ammonium in anaerobic soil. Soil Sci. Soc. Am. J. 42:913-918.

6. Burton, G. W., G. M. Prine, and J. E. Jackson. 1957. Studies of drouth tolerance and water use of several southern grasses. Agron. J. 49:498-503.

7. Canaway, P. M. 1978. Trials of turfgrass wear tolerance and associated factors - a summary of progress 1975-1977. J. Sports Turf Res. Inst. 54:7-14.

8. Carrow, R. N. 1980. Influence of soil compaction on three turfgrass species. Agron. J. 72:1038-1042.

9. Cordukes, W. E. 1968. Compaction. The Golf Super 36(8):20-24.

10. Flocker, W. J., and D. R. Nielsen. 1962. The absorption of nutrient elements by tomatoes associated with levels of bulk density. Soil Sci. Soc. Am. Proc. 26:183-186.

11. Goetze, N. R. 1960. Heavy nitrogen fertilization of cool season turf grasses. Ph.D. Thesis Dissertation Abstr. 21(1)2-3.

12. Gore, A. J. P., R. Cox, and T. M. Davies. 1979. Wear tolerance of turfgrass mixtures. J. Sports Turf Res. Inst. 55:45-68.

13. Gupta, J. P., and I. P. Abrol. 1970. A study of the effect of soil compaction and moisture regimes on the growth and chemical composition of maize plants. Indian Soc. Soil Sci. J. 18(4):397-403.

14. Hemsath, D. L., and A. P. Mazurak. 1974. Seedling growth of sorghum in clay-sand mixtures at various compactions and water contents. Soil Sci. Soc. Am. Proc. 38:387-390.

15. Letey, J., L. H. Stolzy, O. R. Lunt, and V. B. Youngner. 1964. Growth and nutrient uptake of Newport bluegrass as affected by soil oxygen. Plant and Soil 20(2):143-148.

16. ___________, W. C. Morgan, S. T. Richards, and N. Valoras. 1966. Physical soil amendments, soil compaction, irrigation, and wetting agents in turfgrass management. III. Effects on oxygen diffusion rates and root growth. Agron. J. 58:531-535.

17. Madison, J. H. 1971. Principles of turfgrass culture. Van Nostrand Reinhold Co., N. Y.

18. Mathias, E. L., O. L. Bennett, and P. E. Lundberg. 1978. Fertilization effects on yield and N concentration of Midland bermudagrass. Agron. J. 70:973-976.

19. Mitchell, H. L. 1972. Microdetermination of nitrogen in plant tissues. J. Assoc. Offic. Anal. Chemists 1:55.

20. Morris, D. L. 1948. Quantitative determination of carbohydrates with Dreywood's anthrone reagent. Science 107:254-255.

21. Parish, D. H. 1971. Soil conditions as they affect plant establishment, root development, and yield. Effects of compaction on nutrient supply to plants. In K. K. Barnes, W. M. Carleton, H. M. Taylor, R. I. Throckmorton and G. F. Vandenberg (ed.) Compaction of agricultural soils. Am. Soc. Agric. Eng., St. Joseph, Mich.

22. Rieke, P. E., and B. G. Ellis. 1974. Effects of nitrogen fertilization on nitrate movements under turfgrass. Proc. of the Second Int. Turf Res. Conf. p. 120-130.

23. Rimmer, D. L. 1979. Effects of increasing compaction on grass growth in colliery spoil. J. Sports Turf Res. Inst. 55:153-162.

24. Roberts, E. C., and R. M. Pellett. 1964. Potassium helps bluegrass face hot summer. Better Crops 48(2):2-7.

25. Shearman, R. C., and J. B. Beard. 1975. Turfgrass wear tolerance mechanisms: I. Wear tolerance of seven turfgrass species and quantitative methods for determining turfgrass wear injury. Agron. J. 67:208-211.

26. Thurman, P. C., and F. A. Pokorny. 1969. The relationship of several amended soils and compaction rates on vegetative growth, root development and cold resistance of Tifgreen bermudagrass. J. Am. Soc. Hort. Sci. 94:463-465.

27. Van Wijk, A. L. M. 1980. A soil technological study on effectuating and maintaining adequate playing conditions of grass sports fields. Agric. Res. Rep. 903. Centre for Agric. Pub. and Doc., Wageningen.

28. Valoras, N., W. C. Morgan, and J. Letey. 1966. Physical soil amendments, soil compaction, irrigation, and wetting agents in turfgrass management II. Effects on top growth, salinity, and minerals in the tissue. Agron. J. 58:528-531.

29. Warkentin, B. P. 1971. Compaction as it affects soil conditions. Effects of compaction on content and transmission of water in soils. In K. K. Barnes, W. M. Carleton, H. M. Taylor, R. I. Throckmorton, and G. F. Vandenberg (ed.) Compaction of agricultural soils. Am. Soc. Agric. Eng., St. Joseph, Mich.

30. Watson, J. R. 1967. Water requirements as a function of clipping height and frequency. Calif. Turfgrass Culture 17(1):1-3.

31. Wilkinson, J. F., and D. T. Duff. 1972. Rooting of *Poa annua* L., *P. pratensis* L., and *Agrostis palustris* Huds. at three soil bulk densities. Agron. J. 64:66-68.

Table 1. Bulk density, aeration porosity, moisture retention measurements, penetrometer resistance, and soil nitrates.

	Treatment													
	Water Soluble N				Water Insoluble N				LSD (0.05)[+]					
	Low-N		High-N		Low-N		High-N							
Determination	0x	20x	0x	20x	0x	20x	0x	20x	C	NR	NC	CxNR	CxNC	NRxNC
Bulk density (g/cc)														
0-3 cm	1.30	1.37	1.27	1.32	1.26	1.33	1.23	1.34	0.03	ns	ns	ns	ns	ns
3-6 cm	1.25	1.37	1.28	1.37	1.26	1.38	1.24	1.37	ns	ns	ns	ns	ns	ns
% Moisture content by Vol in 0-3 cm depth														
0 bar	41.9	40.6	42.7	38.3	41.8	38.5	43.0	39.3	1.7	ns	ns	ns	ns	ns
-0.10 bar	22.3	23.0	22.5	21.3	20.6	21.9	20.2	22.2	ns	ns	0.8	ns	1.1	ns
-0.33 bar	17.9	19.4	18.5	18.3	16.3	18.9	16.5	18.8	0.9	ns	0.9	ns	ns	ns
Aeration porosity at 0-3 cm depth (%)														
-0.10 bar	19.6	17.7	20.2	17.0	21.2	16.6	22.8	17.1	1.8	ns	ns	ns	ns	ns
Penetrometer resistance (kg/cm^2)														
-0.33 bar	0.71	1.14	0.67	0.89	0.72	1.20	0.64	1.13	0.06	0.06	0.06	ns	0.09	ns

(continued)

Table 1. (continued)

	Treatment													
	Water Soluble N				Water Insoluble N									
	Low-N		High-N		Low-N		High-N		LSD (0.05)[+]					
Determination	0x	20x	0x	20x	0x	20x	0x	20x	C	NR	NC	CxNR	CxNC	NRxNC
Soil nitrates (ppm) at 12 DAF[‡]														
0- 5 cm	5.2	3.6	40.5	14.7	2.1	1.8	2.3	1.8	4.3	4.3	4.3	ns	ns	6.1
5-10 cm	2.1	3.4	1.4	1.3	1.8	2.1	1.9	1.9	ns	0.4	0.4	ns	ns	0.6
10-15 cm	1.9	3.1	4.3	6.4	1.8	2.0	2.1	1.8	ns	1.0	1.0	ns	ns	1.4
15-20 cm	2.2	3.3	3.0	4.7	2.1	2.1	2.2	1.8	ns	ns	0.9	ns	ns	ns
20-25 cm	2.1	2.9	3.2	4.9	1.9	2.7	2.4	1.9	ns	ns	0.6	ns	ns	ns
Soil nitrates (ppm)* at 28 DAF														
0-5 cm	1.7	1.1	1.9	1.3	1.4	1.1	1.0	1.1	ns	ns	0.4	ns	ns	ns
5-10 cm	1.2	1.7	2.0	1.5	1.2	1.3	1.2	1.3	ns	ns	ns	ns	ns	ns
10-15 cm	1.4	2.1	1.7	2.0	1.3	1.4	1.2	1.5	ns	ns	ns	ns	ns	ns
15-20 cm	1.8	2.1	2.2	1.9	1.4	1.3	1.6	1.5	ns	ns	0.5	ns	ns	ns
20-25 cm	1.9	2.3	2.1	3.1	1.0	1.8	1.2	1.1	ns	ns	0.5	ns	ns	ns

[+]C = compaction, NR = nitrogen rate, NC = nitrogen carrier.

[‡]Days after fertilization treatment.

*Data was also collected at DAF = 64 but there were no significant differences at any depth between treatments.

Table 2. Visual quality, verdure, clipping yield, and total nonstructural carbohydrates (%TNC) for perennial ryegrass.

	Treatment													
	Water Soluble N				Water Insoluble N									
	Low-N		High-N		Low-N		High-N		LSD (0.05)[+]					
Determination	0x	20x	0x	20x	0x	20x	0x	20x	C	NR	NC	CxNR	CxNC	NRxNC
Visual quality														
3 d[‡]	9.0	8.5	8.6	8.5	9.0	8.1	8.7	8.0	0.2	ns	ns	ns	0.3	ns
12	9.0	8.4	8.9	8.5	9.0	8.1	8.9	8.2	0.2	ns	ns	ns	ns	ns
28	9.0	8.6	9.0	8.5	8.9	8.5	9.0	8.5	0.1	ns	ns	ns	ns	ns
50	8.1	7.6	8.0	6.7	7.0	7.0	7.5	7.6	ns	ns	ns	ns	ns	ns
Verdure ($g/100\ cm^2$)														
72 d	3.07	3.21	3.54	2.99	2.71	3.49	3.23	3.84	ns	ns	ns	ns	ns	ns
Clipping yield ($g/100\ cm^2$)														
0-22 d	1.82	1.35	1.98	1.37	1.43	1.01	1.45	1.14	0.10	ns	0.10	ns	ns	ns
23-50	1.82	1.24	2.16	1.25	1.65	1.25	1.90	1.67	0.12	0.12	ns	ns	0.22	ns
51-72	1.49	0.91	1.48	0.73	1.35	0.97	1.46	1.06	0.16	ns	ns	ns	ns	ns
Total	5.13	3.50	5.63	3.34	4.43	3.23	4.81	3.87	0.41	ns	ns	ns	ns	ns
%TNC														
35 d	8.9	9.4	12.5	17.9	11.1	9.6	9.9	12.1	ns	1.8	ns	2.5	ns	2.5
72	12.8	9.4	12.0	11.6	13.3	12.6	11.2	17.5	ns	ns	1.9	2.7	2.7	ns

[+] C = compaction, NR = nitrogen rate, NC = nitrogen carrier.

[‡] Days after fertilization.

Table 3. Evapotranspiration, water use efficiency and root weight for perennial ryegrass.

	Treatment													
	Water Soluble N				Water Insoluble N									
	Low-N		High-N		Low-N		High-N		LSD (0.05)+					
Determination	0x	20x	0x	20x	0x	20x	0x	20x	C	NR	NC	CxNR	CxNC	NRxNC
Evapotranspiration														
(cm H_2O used)														
0- 9 d‡	5.9	4.5	4.6	4.0	5.5	4.5	6.4	4.3	0.6	ns	ns	ns	ns	ns
10-22	12.0	9.0	9.3	7.5	10.9	8.0	12.5	8.0	1.0	ns	ns	ns	ns	ns
23-50	27.5	23.4	28.0	18.4	27.8	19.3	30.2	19.9	2.0	ns	ns	ns	ns	1.4
51-72	6.0	4.9	6.1	3.8	6.1	4.4	7.1	4.3	0.4	ns	ns	0.6	ns	ns
Total	51.3	41.8	48.0	33.7	50.3	36.2	56.2	36.6	3.5	ns	ns	ns	ns	5.0
Water use efficiency														
(liters H_2O/gm plant tissue)														
0- 9 d	1.3	1.4	1.0	1.2	1.5	1.8	1.8	1.5	ns	ns	0.2	ns	ns	ns
10-22	1.1	1.2	0.8	0.9	1.3	1.4	1.5	1.2	ns	0.1	0.1	ns	0.1	0.1
23-50	1.1	1.5	1.1	1.2	1.3	1.2	1.2	1.0	ns	0.2	ns	ns	0.3	ns
51-72	2.1	3.1	2.3	3.2	2.7	2.1	2.3	1.9	ns	ns	ns	ns	ns	ns
Total	1.3	1.4	0.9	1.2	1.3	1.2	1.4	1.0	ns	0.1	ns	0.1	ns	ns
Root weight														
(mg/100 cm^2)														
Total	687	610	687	326	571	481	866	534	80	ns	ns	113	ns	113
0- 5 cm	259	256	238	165	245	192	353	275	33	ns	33	ns	ns	47
5-15 cm	245	227	268	108	198	184	299	155	42	ns	ns	60	ns	60
15-25 cm	183	127	181	53	128	105	214	104	33	ns	ns	47	ns	47

+C = compaction, NR = nitrogen rate, NC = nitrogen carrier.

‡Days after fertilization treatment.

Table 4. **Percent N in leaf tissue**, N-use per unit area, and percent N recovery for perennial ryegrass.

	Treatment													
	Water Soluble N				Water Insoluble N									
	Low-N		High-N		Low-N		High-N		LSD (0.05)[+]					
Determination	0x	20x	0x	20x	0x	20x	0x	20x	C	NR	NC	CxNR	CxNC	NRxNC
% N in leaf **tissue**[‡]														
3 d	3.6	3.9	4.2	3.8	3.7	3.5	3.5	3.1	ns	ns	0.4	ns	ns	ns
9	3.5	2.9	3.1	2.8	2.4	2.6	2.9	2.5	ns	ns	0.4	ns	ns	ns
14	3.7	4.0	3.8	3.8	3.6	3.6	3.7	3.4	ns	ns	ns	ns	ns	ns
42	3.6	3.6	4.7	3.8	4.2	4.5	4.1	4.6	ns	ns	ns	ns	ns	ns
72	4.8	5.0	5.3	5.0	5.4	5.7	5.4	4.9	ns	ns	ns	ns	ns	ns
N-use per unit area (mg N used/100 cm^2)														
0- 9 d	46	28	49	32	37	28	34	26	3	ns	3	ns	4	ns
10-22	37	28	39	27	25	17	27	19	3	ns	3	ns	ns	ns
23-50	69	42	86	45	61	46	71	65	6	6	ns	ns	8	ns
51-72	51	31	55	26	46	33	49	36	4	ns	ns	ns	6	ns
Total	202	129	228	131	168	123	182	146	9	9	9	ns	12	ns
% N recovery (mg N used/mg N applied) x 100														
Total	405	259	228	131	337	246	182	146	13.9	13.9	13.9	19.7	19.7	ns

[+]C = compaction, NR = nitrogen rate, NC = nitrogen carrier.

[‡]Other sampling dates were 22, 28, 35, 50, 58 and 64 DAF. There were few significant **differences.**

TABLE CAPTIONS

Table 1. Bulk density, aeration porosity, moisture retention measurements, penetrometer resistance, and soil nitrates.

Table 2. Visual quality, verdure, clipping yield, and total nonstructural carbohydrates (%TNC) for perennial ryegrass.

Table 3. Evapotranspiration, water use efficiency and root weight for perennial ryegrass.

Table 4. Percent N in leaf tissue, N-use per unit area, and percent N recovery for perennial ryegrass.

Influence of Soil Compaction on N Utilization in Tall Fescue

M. J. Sills and R. N. Carrow

ABSTRACT

Soil compaction is a problem in sport turf areas. In this field study the influence of soil compaction on morphological and physiological aspects of *Festuca arundinacea* Schreb. 'Kentucky 31' were investigated. The turfgrass was subjected to three compaction treatments with a smooth, power roller: 1) 0x - no compaction, 2) 10x - 10 passes a week for 4 weeks, 3) 20x - 20 passes a week for 4 weeks. The turfgrass received two fertilization treatments: 1) 0.38 kg N/100 m^2 per application with three applications, 2) 0.75 kg N/100 m^2 per application with three applications. A fine, montmorillonitic mesic Aquic Arguidoll soil was used.

Increasing compaction increased bulk density, water retention, and soil strength while decreasing aeration porosity. Visual quality, clipping yield, N use per unit area, percent N recovery, and root growth declined as compaction increased. Visual quality, clipping yield, percent N in leaf tissue, and N uptake per 100 cm^2 increased with increasing N-rates while percent N recovery declined. Total nonstructural carbohydrates were unaffected. There was a detrimental effect on root weight at the high N-rate with compaction. Compaction altered soil physical properties which affected plant growth and influenced plant and soil responses to N fertilization.

Additional index words: *Festuca arundinacea* Schreb., Verdure, Bulk density, Aeration porosity, Clipping yield, Soil strength.

Most turfgrass sites are subjected to some degree of foot or vehicular traffic. Traffic related stresses are wear and soil compaction. Wear injury occurs from physical abrasion and tearing of above ground plant parts (2). Compaction influences soil bulk density, strength, aeration, and water relationships, which in turn may affect plant growth. Madison (12) noted that soil compaction was the most serious turf problem on recreational sites.

Research investigations have demonstrated the adverse effects of compaction on turfgrasses. Turf root growth declines with increasing compaction (5, 11, 18, 20). Reduced plant density, cover, and verdure have been reported (4). Also, Thurman (20) and Valoras (22) found that compaction reduced shoot growth of bermudagrass.

Nitrogen (N) fertilization is a major cultural practice on high maintenance sport turfs. Much research has been conducted on proper N-fertilization (12). However, limited literature exists on the influence of soil compaction on turfgrass utilization of N.

The objective of this study was to determine the influence of soil compaction on N-utilization from a water soluble N-carrier on tall fescue.

MATERIALS AND METHODS

This 1980 field study was established on a Chase silt loam (fine, montmorillonitic, mesic Aquic Arguidolls). The turfgrass was a three year old stand of Festuca arundinacea Schreb. 'Kentucky 31' tall fescue. Irrigation was applied at 3.5 cm once a week to prevent moisture stress.

Plot size was 3.0 x 1.1 m with three replications per treatment in a 2 x 3 factorial, randomized, complete block design. Each plot received one of six compaction and N-rate treatments (Table 1). Compaction treatments were: a) 0x - none; b) 10x - 10 passes a week for 4 weeks with a power roller, then 2 passes a week for 5 weeks to maintain compaction; c) 20x - 20 passes a week for 4 weeks with a power roller, then 4 passes a week for 5 weeks to maintain compaction. Compaction treatments were applied with a smooth, power roller that exerted 2.5 kg/cm^2 static pressure with all passes made on the same day of the week. Soil for all treatments was irrigated to saturation 24 hours before each compaction. Compaction applied in this study was similar to that received on athletic turfs (4). The smooth, power roller was used to minimize the effects of wear. Slight wear was present after applications made in the late part of July due to heat stress and thus a less vigorous resilient turf. Recovery from wear was apparent 2-3 days after the compaction treatment.

Fertilization treatments were: a) 0.38 kg N/100 m^2 per application with three applications; b) 0.75 kg N/100 m^2 per application with three applications. Nitrogen was applied as urea (45-0-0) on 25 June, 23 July, and 5 Sept.

Clippings were collected weekly, dried at 65 C for 24 hours, weighed and analyzed for percent N in the tissue from a micro-Kjeldahl digestion (14) using a selective, NH_3^- ion electrode (1) (Appendix A). Verdure, shoot density, and total nonstructural carbohydrates (TNC) were determined from two samples (5.4 cm diam) per plot. Samples were collected before 1000 hours, dried at 100 C for one hour, then 60 C for 24 hours. The TNC levels were determined by the method of Morris (15). Visual quality ratings were based on turfgrass color, density, and uniformity. A scale of (9 = ideal, 6.5 = acceptable, 1 = no live turf) was used. Root weights were determined by combining four cores (2.0 cm diam each) per plot for each depth, washing, drying at 65 C for 24 hours, and weighing.

Soil NO_3^- was measured weekly from two cores (2.0 cm diam) per plot. Samples were separated by depth, dried at 30 C for 24 hours, then sieved to pass through a 20 mesh screen. A 10 g sample was analyzed using a selective NO_3^- electrode (1).

Soil physical measurements were obtained in August to determine the degree of compaction. Bulk density, moisture retention, and aeration porosity were from one core (5.4 cm diam x 3 cm) at each depth (0-3 cm, 3-6 cm) per plot. Penetrometer resistance was measured for soil strength at the surface at field capacity.

RESULTS AND DISCUSSION

Soil Physical Properties

Soil physical properties were affected by compaction (Table 1). Since no differences occurred due to N-rate, values for compaction treatments were averaged over both N-rates. Increasing compaction resulted in higher bulk density in the surface 0-3 cm and an altered moisture release curve. Aeration porosity at -0.10 bar moisture content in the surface 0-3 cm declined from 14.1 to 10.6. Due to the moderately slow drainage, aeration porosity at -0.10 bar was assumed to be the aeration status the turf was most subjected to after irrigation. Madison (12) recommended a minimum of 10% non-capillary pore space after compaction for sports-turf areas. Penetrometer values increased 2.2 fold when going from 0x to 20x compaction. This is in agreement with Hemsath (9) who found that penetrometer resistance increased as bulk density increased.

Turfgrass Growth Responses

Compaction is an indirect stress on turfgrass by influencing soil physical properties such as soil strength, aeration, and moisture retention. These altered physical properties may adversely affect plant growth activity.

Shoot growth. Visual quality declined with increasing compaction regardless of N-rate (Table 2). A higher N-rate resulted in better quality turf and did offset some of the compaction effects in Oct. The decline in turf quality as compaction increased was similar to trends observed by other investigators (2, 3, 5, 7, 20, 21, 22).

Neither compaction or N-rate influenced plant density and verdure at the 5% significance level (Table 2). However, a reduction in verdure was noted in Sept. at the 10% level. The reduced verdure would be important in wear tolerance because turfgrasses exhibit better wear tolerance at higher plant density and verdure (2, 3). Carrow (4) observed a decrease in verdure of Kentucky bluegrass and tall fescue under compaction treatments.

Clipping yield declined with increasing compaction from 0x to 10x but this was most apparent at the low N-rate (Table 2). An increase in N-rate reduced most of the effects of compaction on clipping yield. Thurman (20) and Valoras (22) reported that compaction reduced shoot growth of bermudagrass. Van Wijk et al. (21) found that above ground growth was reduced at soil oxygen diffusion rates (ODR) of below 10×10^{-8} g cm^{-2} min^{-1} which can result from compaction.

All treatments exhibited similar low TNC levels (Table 2). Carrow (4) found that three species of cool season turfgrasses demonstrated a TNC reduction as compaction increased. Kentucky bluegrass TNC decreased 50%;

perennial ryegrass and tall fescue, 28 and 35%, respectively. In our study any influences of compaction or N-rate may have been masked by the prolonged high temperature stress with many daily highs in excess of 38 C. Carbohydrate reserves are desirable since they serve as an immediate source of carbohydrates for regrowth following a stress (2).

Root growth. In this study, compaction was applied in the summer when root growth was at a minimum, since the majority of tall fescue rooting occurs in the spring and fall. Rooting data on Sept. 3 did not reveal any differences due to treatments (Table 3). Apparently compaction and N-rate did not affect summer root deterioration as has been reported to occur on tall fescue (4). The unusually high temperatures during July and Aug. may have had a greater influence than the treatments.

The Oct. sampling date reflects fall root growth and at high N total root weight was affected by compaction. Root weight decreased 48% from the 0x to 10x compaction and then increased slightly. Carrow (4) evaluated three turfgrass species with respect to rooting under compaction and noted that root growth does not necessarily decrease linearly with compaction. Under low N, compaction did not reduce total rooting.

Root distribution was altered by compaction and N-rate. Increasing compaction caused a decline in root growth in the 5-10, 10-20, and 20-30 cm soil zones, particularly under the higher N-rate. Also, most of the responses were between 0x and 10x compaction levels. Madison (12) noted that when N was adequate for plant growth an increase in N could result in decreased rooting. The results suggest that excess N coupled with compaction has a detrimental synergistic effect on root growth.

Nitrogen Responses

Plant nitrogen. Compaction did not affect the percent N in leaf tissue but the higher N-rate increased percent leaf N (Table 4). The plant N levels are in agreement with Roberts (19) who reported 2.8% N for low fertility grass, 3.5% for moderate fertility grass, and 4.4 to 4.9% for bluegrass receiving excessive N. Other investigators found that N concentration increased with increased bulk density in maize (8) and tomatoes (6). However, Letey et al. (10) found that N concentration increased with increased oxygen levels.

Early in the summer compaction reduced N-use per unit area of turf by 13 to 39% (Table 4). Evidently, decreased shoot growth of compacted plots reduced the total N utilized by the turf stand on an area basis. Also, reduced root growth may have decreased the volume of soil for N uptake. This would suggest less efficient use of applied N on compacted sites, which was confirmed by the percent N recovery data. As compaction increased between 0x and 10x the percent N recovered declined by 31 and 10%, respectively, for the low and high N-rates.

While additional applied N increased N-use per unit area the actual percent N recovery was less at the higher N level. Thus, N-use efficiency actually decreased as N-rate increased, irrespective of compaction level. Mathias (13) found that higher N-rates on a non-compacted soil increased N concentration in 'Midland' bermudagrass, while the percent recovery of applied N decreased. Madison (12) noted that each added increment of a mineral increases yield, but the increase is smaller with each added increment. Thus, the amount of N used for each added increment of N is smaller.

Soil nitrates. Soil NO_3^- levels in the 0-5 cm zone tended to be higher with increasing compaction but only under the high N-rate (Table 4). This was apparent early in the study and on the last two sample dates. One reason that soil NO_3^- levels may have been higher could be due to the reduced plant N use per unit area under compaction. Possibly, the aeration was limiting for maximum root viability. Also, compaction may have reduced mass flow which is a significant means of soil NO_3^- transport (16). With minor exceptions, soil NO_3^- levels were not affected at other sampling depths due to any treatment (Table 4). Soil NO_3^- levels in this study were low but within the range noted by Rieke and Ellis (17).

Soil compaction adversely altered the soil physical properties which then reduced turfgrass quality, clipping yield, and root growth. In addition, compaction affected plant and soil responses to N fertilization, which is a major cultural practice on turf. The higher N-rate tended to alleviate some of the shoot growth reductions caused by compaction. However, the visual quality and clipping yield data indicate that higher N did not entirely compensate for the compaction stress. At the same time the combination of compaction and higher N resulted in a decline in fall root growth.

Alterations in shoot and root growth appeared to influence N utilization. Compaction caused a reduction of N-use per unit area as well as percent N recovery of applied N. Application of higher N did appear to improve N-use per unit area and percent N recovery of the compacted plots when compared to the compacted treatments low N.

Data in this study would indicate that compacted turfgrass sites do not respond to N fertilization in the same degree as uncompacted stands. Nitrogen utilization will be less efficient and turfgrass less responsive. If N-rates are too high, reduced rooting may occur. Compacted and uncompacted sites should be managed with separate fertilization programs.

LITERATURE CITED

1. Anonymous. 1978. Analytical methods guide. 9th ed. Orion Res., Inc., Cambridge, Mass.

2. Beard, James B. 1973. Turfgrass: science and culture. Prentice-Hall, Inc., Englewood Cliffs, N. J.

3. Canaway, P. M. 1978. Trials of turfgrass wear tolerance and associated factors - a summary of progress 1975-1977. J. Sports Turf Res. Inst. 54:7-14.

4. Carrow, R. N. 1980. Influence of soil compaction on three turfgrass species. Agron. J. 72:1038-1042.

5. Cordukes, W. E. 1968. Compaction. The Golf Super. 36(8):20-24.

6. Flocker, W. J., and D. R. Nielsen. 1962. The absorption of nutrient elements by tomatoes associated with levels of bulk density. Soil Sci. Soc. Am. Proc. 26:183-186.

7. Gore, A. J. P., R. Cox, and T. M. Davies. 1979. Wear tolerance of turfgrass mixtures. J. Sports Turf Res. Inst. 55:45-68.

8. Gupta, J. P., and I. P. Abrol. 1970. A study of the effect of soil compaction and moisture regimes on the growth and chemical composition of maize plants. Indian Soc. Soil Sci. J. 18(4):397-403.

9. Hemsath, D. L., and A. P. Mazurak. 1974. Seedling growth of sorghum in clay-sand mixtures at various compactions and water contents. Soil Sci. Soc. Am. Proc. 38:387-390.

10. Letey, J., L. H. Stolzy, O. R. Lunt, and V. B. Youngner. 1964. Growth and nutrient uptake of Newport bluegrass as affected by soil oxygen. Plant and Soil 20(2):143-148.

11. ___________, W. C. Morgan, S. T. Richards, and N. Valoras. 1966. Physical soil amendments, soil compaction, irrigation, and wetting agents in turfgrass management. III. Effects on oxygen diffusion rates and root growth. Agron. J. 58:531-535.

12. Madison, J. H. 1971. Principles of turfgrass culture. Van Nostrand Reinhold Co., New York, N. Y.

13. Mathias, E. L., O. L. Bennett, and P. E. Lundberg. 1978. Fertilization effects on yield and N concentration of Midland bermudagrass. Agron. J. 70:973-976.

14. Mitchell, H. L. 1972. Microdetermination of nitrogen in plant tissues. J. Assoc. Offic. Anal. Chemists 1:55.

15. Morris, D. L. 1948. Quantitative determination of carbohydrates with Dreywood's anthrone reagent. Science 107:254-255.

16. Parish, D. H. 1971. Soil conditions as they affect plant establishment, root development and yield. Effects of compaction on nutrient supply to plants. In K. K. Barnes, W. M. Carleton, H. M. Taylor, R. I. Throckmorton, and G. F. Vandenberg (ed.) Compaction of agricultural soils. Am. Soc. Agric. Eng., St. Joseph, Mich.

17. Rieke, P. E., and B. G. Ellis. 1974. Effects of nitrogen fertilization on nitrate movements under turfgrass. Proc. of the Second Int. Turf Res. Conf. p. 120-130.

18. Rimmer, D. L. 1979. Effects of increasing compaction on grass growth in colliery spoil. J. Sports Turf Res. Inst. 55:153-162.

19. Roberts, E. C., and R. M. Pellett. 1964. Potassium helps bluegrass face hot summer. Better Crops 48(2):2-7.

20. Thurman, P. C., and F. A. Pokorny. 1969. The relationship of several amended soils and compaction rates on vegetative growth, root development and cold resistance of Tifgreen bermudagrass. J. Am. Soc. Hort. Sci. 94:463-465.

21. Van Wijk, A. L. M. 1980. A soil technological study on effectuating and maintaining adequate playing conditions of grass sports fields. Agric. Res. Rep. 903. Centre for Agric. Pub. and Doc., Wageningen.

22. Valoras, N., W. C. Morgan, and J. Letey. 1966. Physical soil amendments, soil compaction, irrigation, and wetting agents in turfgrass management II. Effects on top growth, salinity, and minerals in the tissue. Agron. J. 58:528-531.

Table 1. Bulk density, aeration porosity, moisture retention and penetrometer resistance determinations.

	Compaction			LSD (0.05)+
Determination	0x	10x	20x	C
Bulk density (g/cc)				
0-3 cm	1.07	1.18	1.20	0.08
3-6 cm	1.20	1.23	1.25	ns
% Moisture content by vol. in 0-3 cm depth				
0 bar	46.9	46.9	46.9	ns
-0.10 bar	34.3	34.6	35.7	1.2
-0.33 bar	32.3	32.9	34.2	1.1
% Aeration porosity at -0.10 bar				
0-3 cm	14.1	11.6	10.6	0.4
3-6 cm	12.5	12.1	11.0	ns
Penetrometer resistance (kg/cm^2)				
-0.33 bar	0.79	1.26	1.70	0.20

+C = compaction. Nitrogen rate (NR) and CxNR responses were not significant. Thus, compaction responses are averaged over NR.

Table 2. Visual quality, verdure, shoot density, clipping yield, and total nonstructural carbohydrate (%TNC) measurements for tall fescue.

	Treatment						LSD (0.05)+		
	Low N-Rate			High N-Rate					
Determination	0x	10x	20x	0x	10x	20x	C	NR	CxNR
Visual quality									
7/20	7.2	6.3	6.2	7.2	7.0	6.4	0.5	ns	ns
9/ 8	6.8	6.4	6.2	7.3	6.8	6.5	0.5	0.4	ns
10/14	6.3	6.5	6.2	7.5	7.3	7.0	0.2	0.2	ns
Verdure ($g/100\ cm^2$)									
initial	28.3	--	--	--	--	--	--	--	--
7/27	31.0	24.0	27.3	26.9	22.1	22.9	ns	ns	ns
9/ 3	43.0	35.8	29.3	38.0	39.8	34.7	ns	ns	ns
Shoot density ($shoots/100\ cm^2$)									
9/ 8	64.2	53.3	63.3	62.5	53.7	53.7	ns	ns	ns
10/14	61.2	48.1	62.5	74.3	60.3	47.2	ns	ns	ns
Clipping yield ($g/100\ cm^2$)									
6/30-7/27	0.93	0.56	0.64	0.93	0.77	0.86	0.11	0.09	ns
7/28-9/ 3	0.73	0.56	0.56	1.02	0.93	0.85	ns	0.14	ns
Total	1.65	1.12	1.20	1.95	1.70	1.72	0.28	0.23	ns
%TNC									
initial	9.4	--	--	--	--	--	--	--	--
9/3	9.5	6.9	11.2	9.1	8.0	8.5	ns	ns	ns

+C = compaction, NR = nitrogen rate.

Table 3. Root weight by depth and total root weight for tall fescue.

	Treatment								
	Low N-Rate			High N-Rate			LSD (0.05)+		
Determination	0x	10x	20x	0x	10x	20x	C	NR	CxNR
Root weight ($mg/100\ cm^2$) Taken 9/3									
Total	3276	2956	3136	3384	2583	2763	ns	ns	ns
0- 5 cm	1200	1097	1234	1165	841	1028	ns	ns	ns
5-10 cm	539	560	650	720	524	585	ns	ns	ns
10-20 cm	882	751	759	1007	900	708	ns	ns	ns
20-30 cm	655	548	493	492	318	442	ns	ns	ns
Root weight ($mg/100\ cm^2$) Taken 10/14									
Total	3379	3147	3383	4546	2367	3350	527	ns	745
0- 5 cm	1002	1290	1071	1685	849	1727	ns	ns	637
5-10 cm	751	674	790	919	392	547	111	90	157
10-20 cm	908	741	944	1063	687	669	201	ns	ns
20-30 cm	719	442	578	879	439	407	206	ns	ns

+C = compaction, NR = nitrogen rate.

Table 4. Percent N in leaf tissue, N-use per unit area, percent N recovery, and soil nitrates for tall fescue.

	Treatment								
	Low N-Rate			High N-Rate			LSD (0.05)+		
Determination	0x	10x	20x	0x	10x	20x	C	NR	CxNR
% N in leaf tissue									
6/30	3.3	3.3	3.0	3.0	3.2	3.3	ns	ns	0.3
7/ 6	3.9	4.0	3.6	4.2	4.4	4.3	ns	0.4	ns
7/14	3.8	3.7	3.6	4.1	3.9	4.0	ns	0.2	ns
7/20	3.3	3.3	3.2	3.4	3.6	3.4	ns	ns	ns
7/27	3.2	3.5	3.3	3.5	3.9	3.8	ns	0.3	ns
8/10	3.3	3.3	3.2	3.1	3.7	3.7	ns	0.3	ns
8/18	3.5	3.7	3.6	3.9	3.8	3.8	ns	0.2	ns
8/26	3.7	3.9	3.9	4.2	4.1	4.6	ns	0.3	ns
9/ 3	3.3	3.9	3.8	4.1	3.8	3.9	ns	ns	ns
N-use per unit area (mg N used/100 cm^2)									
6/30-7/27	33.1	20.1	21.4	34.8	30.3	33.1	2.0	4.2	ns
7/28-9/ 3	25.1	20.1	19.7	37.7	35.2	33.2	ns	6.6	ns
Total	58.2	40.2	41.1	72.5	65.5	66.3	ns	10.4	ns
% N-recovery (mg N used/mg N applied) x 100									
Total	51.1	35.3	36.0	32.2	29.1	29.5	0.1	0.1	ns
Soil Nitrates‡ (ppm) 0-5 cm Depth*									
7/ 1	1.6	8.8	1.9	4.3	3.2	8.8	1.4	1.1	2.2
7/ 8	1.3	1.5	1.3	1.9	1.2	1.3	ns	ns	ns
7/25	2.8	2.1	1.7	8.1	4.9	9.3	ns	2.2	ns
8/15	1.1	1.1	1.0	1.1	1.3	1.1	0.1	0.1	ns
8/29	0.9	0.9	0.9	0.9	1.0	1.4	0.1	0.1	0.2
9/ 4	1.3	1.6	1.4	2.0	4.1	4.2	0.9	0.7	1.3

+C = compaction, NR = nitrogen rate.

‡Fertilization dates were 6/26 and 7/23.

*Other depths sampled were 5-10, 10-15, 15-20 and 25-30 cm with few s.d.

TABLE CAPTIONS

Table 1. Bulk density, aeration porosity, moisture retention and penetrometer resistance determinations.

Table 2. Visual quality, verdure, shoot density, clipping yield, and total nonstructural carbohydrate (%TNC) measurements for tall fescue.

Table 3. Root weight by depth and total root weight for tall fescue.

Table 4. Percent N in leaf tissue, N-use per unit area, percent N recovery, and soil nitrates for tall fescue.

APPENDIX A

Kjeldahl digestion followed the procedure outlined by Mitchell. The digestate was then analyzed using a method modified from an Orion Methods Manual. The digestate from a 50 mg sample was brought to pH 12 with NaOH, diluted to 50 ml, and then analyzed directly with an ammonium electrode. Millivolt values were converted to percent N using a standard curve.

ACKNOWLEDGMENTS

The writer wishes to express sincere thanks to Dr. R. N. Carrow for his guidance and the use of his laboratory facilities throughout this study.

Thanks are also extended to Dr. H. Khatamian and Dr. R. Keen for their guidance and support, and to Bob Bruce and Mark Wagoner for assistance in assembling the greenhouse facilities.

INFLUENCE OF SOIL COMPACTION ON N UTILIZATION IN COOL SEASON TURFGRASSES

by

MELANIE SILLS

B.S., Kansas State University, 1979

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Horticulture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1981

Soil compaction is a problem in many turf areas. The objective of this study was to determine the influence of soil compaction on N and water utilization in cool season turfgrasses from water soluble and water insoluble N-carriers.

A greenhouse study subjected *Lolium perenne* L. 'Pennfine' to two compaction treatments with an 11.5 kg falling weight: a) 0x - none, b) 20x - weight was dropped 20 times from a height of 36.8 cm. Fertilization rate treatments were 0.5 and 1.0 kg N/100 m^2. Nitrogen-carrier treatments were water soluble N (NH_4NO_3) and water insoluble N (IBDU).

A field study subjected *Festuca arundinacea* Schreb. 'Kentucky 31' to three compaction treatments with a smooth, power roller: a) 0x - no compaction, b) 10x - 10 passes a week, c) 20x - 20 passes a week. The turfgrass received two fertilization treatments: a) 0.38 kg N/100 m^2 per application with three applications, b) 0.75 kg N/100 m^2 per application with three applications.

Increasing compaction increased bulk density, water retention, and soil strength while decreasing aeration porosity. Visual quality, clipping yield, N-use per unit area, percent N recovery, evapotranspiration, and root growth declined as compaction increased. Visual quality, clipping yield, percent N in leaf tissue, total water use efficiency, and N-use per unit area increased with increasing N-rates while percent N recovery declined. Clipping yield, N-use per unit area, percent N recovery, and water use efficiency were higher with a water soluble N-carrier. The most detrimental effect of compaction was on root weight at a high water soluble N application.