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Breeding, Evaluation and Culture of Buffalograss for Golf Course Turf

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I. EXECUTIVE REPORT

1. GRASSES DUE TO BE COMMERCIALIZED

The Number 1 genotype throughout the country and in our research plots at the University of Nebraska was NE 84-609. This buffalograss is a southern type with good adaptation in the south and potential adaptation in the basic north. We are proceeding with developing a crop registration, a plant patent, and release of NE 84-609 for use in the southern United States.

2. COMMERCIALIZATION--SEEDED BUFFALOGRASS

An agreement has been received from a consortium of companies which includes Farmers Marketing Corporation, Yuma, Arizona; Arrow Seed, Broken Bow, Nebraska; and Johnston Seed, Enid, Oklahoma. This agreement calls for the development of a new seeded turf-type buffalograss using plant material from the University of Nebraska.

3. COMMERCIALIZATION--VEGETATIVE BUFFALOGRASS

We have been contacted by Crenshaw/Douget, Inc., that has an interest in NE 84-609 for use in the Texas market. It is believed that an agreement will be received shortly from this company that may be worthy of consideration.

4. COMMERCIAL TESTING/EVALUATION

During 1990, the University of Nebraska will work with golf courses and sod producers in evaluating the performance and potential of vegetative buffalograsses in various locations. It will be our effort to make these planned releases available under agreement to individuals who would have the most positive effect on our project. We will be working with the United States Golf Association and the Golf Course Superintendents Association of America on this portion of the project.

5. BUFFALOGRASS VEGETATIVE INCREASE

Establishment of vegetative increase areas started in 1987 and has continued with additional material added each year. To date, seventeen cultivars have been increased for a total of 83,000 ft^2. This area is used to provide plant material for advanced testing studies.

6. DEMONSTRATION AND STUDY PLOTS

Texas A & M Univ.; Milt Engelke - Dallas, TX: Plugs of several buffalograss selections (Prairie, Texoka, NE 84-409, NE 84-609, NE 84-315, NE 84-304 and NE 85-378) planted May 18, 1988 were observed at the Texas Agricultural Experimental Station in Dallas. Turf quality data values showed NE 84-609, NE 84-304 and Prairie as exhibiting good turf-type qualities. Prairie and NE 84-609 exhibited the best turf color throughout the season.

7. BUFFALOGRASS BIOTECHNOLOGY

After a great deal of preliminary experimentation, a breakthrough has been made on the buffalograss biotechnology project. Callus has been initiated from stolon tips of the female cultivars NE 84-609, NE 85-378 and NE 84-315. This is an important discovery for four reasons: (1) these three cultivars are projected as being patented in the early 1990's; (2) the explant utilized is clonal material; (3) stolon tips are easily handled and can be grown in an unlimited supply in the greenhouse; and (4) callus is being induced from the aesthetically pleasing female plant.

8. BUFFALOGRASS WATER USE RATES

Preliminary results show experimental varieties NE 84-315 and NE 84-409 along with the common variety Homes exhibited the lowest 48-hour water use rates at 10.33, 11.37 and 11.76 mm, respectively. Varieties NE 84-304, NE 84-609 and Texoka showed relatively higher 48-hour rates at 11.89, 12.61 and 12.62 mm, respectively. All the varieties tested show a substantial water savings compared to the most commonly used turfgrasses which have water use rates ranging from 12 to over 20 mm per 48-hour cycle.

9. IMAGE ANALYSIS

The application of remote sensing and digital image techniques to determine root measurements automates the process of data collection and analysis thereby decreasing processing time and increasing accuracy. Time and manual input by operator was reduced by 50% with the computer method. Processing of digital images by different operators was possible without loss of accuracy.

10. FAIRWAY MANAGEMENT STUDY

Observations of research plots since 1985 suggests that buffalograss could be used on golf course fairways with significant savings of water, fertilizer, pesticides and mowing. Results from studies indicated a savings of greater than 50% for water and fertilizer use. A study was initiated to evaluate buffalograss turfgrass quality and performance under modified fairway maintenance schedules and playing conditions.

11. MECHANICAL TURF PLUGGER FOR BUFFALOGRASS

A mechanical turf plugger was developed by retrofitting a Ryan GA 30 aerator with plugging tines. The mechanical turf plugger was evaluated under field conditions to determine the adaptation of this method of plugging for extracting buffalograss [*Buchloe dactyloides* (Nutt.) Engelm.] plugs.

12. BUFFALOGRASS INSECT STUDIES

At the present time, studies are underway at the John Seaton Anderson Turfgrass Facility, located at Mead, Nebraska, to secure a better understanding of mealybug biology, ecology, geographic distribution, seasonal abundance and injury potential in buffalograss.

II. BUFFALOGRASS PROPAGATION

A. BUFFALOGRASS VEGETATIVE INCREASE

The purpose of this planting is to increase plant material of buffalograss clones which have shown outstanding turf type characteristics. Plant material was selected from the 1986 and 1987 Advanced Increase areas and increased to 50 ft x 100 ft plots. Establishment of area started in 1987 and has continued with additional material added each year. To date, seventeen cultivars have been increased for a total of 83,000 ft^2. This area is used to provide plant material for advanced testing studies.

B. DEMONSTRATION AND STUDY PLOTS

1. University of Nebraska Sites

The following sites have been established by the University of Nebraska as test/demonstration plots. The cooperator has agreed to provide us with establishment and performance information on a yearly basis. These studies generally are not replicated nor do they have extensive maintenance practices performed on them, unless noted. Cooperators have signed the Agreement for Release of Plant Material for Evaluation developed by the USGA research committee.

Antelope Co. Ext. Service; Dewey Teel - Neligh, NE: Demonstration plot of NE 84-315 was established during the summer of 1989 at the Centennial Gardens in Neligh, Nebraska.

UNL Animal Science Bldg; Terry Riordan - Lincoln, NE: Area was established in 1987 and had established nicely during the 1988 drought. During the spring of 1989 an over-application of weed control had an adverse effect on the stand. Although there was loss of plant material, actively growing buffalograss was observed approximately 4 weeks after application. By the end of the growing season there was no visible evidence of the application. Genotypes NE 84-378 and NE 84-609 had performed well throughout the season.

Chadron State College; Jay Druecker - Chadron, NE: Originally established in 1988 this study has received no fertilizer, herbicide, irrigation or mowing treatments since initial planting. Percent plot density for 1988 and 1989 season, respectively, was as follows: NE 85-378 (63/52), NE 84-609 (97/43), NE 84-409 (76/28), NE 84-304 (76/25), NE 84-315 (31/45) and Texoka (85/61). Decline in percent density for most of the plots was not surprising given both growing seasons were dryer than normal. Several of the clones exhibiting decline were southern selections and were not expected to be as winter hardy. The selection of NE 84-315 exhibited an increase in coverage indicating potential for higher tolerance to minimal maintenance schedules and winter conditions.

Cook College; C. Funk - New Brunswick, NJ: Report forthcoming.

Nebr. Northeast Research and Extenstion Center; Terry Gompert - Center, NE: Study was established early in the 1989 growing season. As of October, plots of NE 84-304 and NE 84-409 were 90% covered. The other cultivars including NE 85-378, NE 84-609, NE 84-315 and Texoka were only 20-30% covered.

Minn. Ext. Serv. - Hennepin Co.; Bob Mugaas - Golden Valley, MN: Future site for demonstration plots.

Nuckolls Co. Ext. Serv.; Chet Hawley - Nelson, NE: Report forthcoming.

North Carolina State Univ.; Art Bruneau - Raleigh, NC: Report forthcoming.

Texas A & M Univ.; Milt Engelke - Dallas, TX: Plugs of several buffalograss selections (Prairie, Texoka, NE 84-409, NE 84-609, NE 84-315, NE 84-304 and NE 85-378) planted May 18, 1988 were observed at the Texas Agricultural Experimental Station in Dallas. Plots were maintained at a mowing height of 2.5 inches and fertilized with 2 lb N/1000 ft^2. Clones were evaluated for the following traits: percent coverage, stolon number and elongation rate, percent greenup, relative frost tolerance and turf quality and color.

Percent coverage data from June 23, 1988, to April 8, 1989, (8 readings) showed Prairie and NE 84-609 as almost 100% covered by February 26, 1989. The other clones ranged from 55% (NE 84-315) to 85% (NE 84-409) covered. At the last reading Prairie was 100% covered while NE 84-609 decreased to 88% covered. Remaining clones were in the mid 80 percentile range with the exception of NE 84-315 which was only 70% covered. Stolon number at 49 days resulted in Prairie and NE 84-609 as showing 17 and 10 stolons per plant, respectively, compared to 4-8 stolons for other clones. Longest stolon at 49, 57 and 70 days showed NE 84-609 as measuring the longest compared to the other clones. Percent greenup beginning March 15 and ending April 15 indicated that NE 84-609 was considerably ahead compared to the other clones for all 10 data collection periods. Relative frost tolerance showed Prairie, NE 84-304, NE 84-315 and NE 84-609 as tolerating a late spring frost best. Turf quality data values showed NE 84-609, NE 84-304 and Prairie as exhibiting good turf-type qualities. Prairie and NE 84-609 exhibited the best turf color throughout the season.

Overall, Nebraska selection NE 84-609 performed as well and in some cases better than Prairie. The other selections showing promise were NE 84-304 and NE 84-409.

West Central Ext. Center; Dale Lindgren - North Platte, NE: Study was established July 19, 1989. To date, the NE 84-609 plots have filled in 60% while the other cultivars (NE 84-409, NE 84-304, NE 85-378, NE 84-315 and Texoka) were 5-20% filled. Plots received irrigation every 7-10 days.

2. Non University Sites

The following cooperators are working with the project leader to develop various aspects of buffalograss breeding and culture. The cooperators have signed the Agreement For Testing Plant Varieties Between USGA Sponsored Breeder and Commercial Seed/Sod Producer developed by the USGA research committee.

Aurora McTurf; Dick & Elsie Frogge - Aurora, NE

B-Four Corp.; David Huff - Houston, TX

Coastal Plain Exp. Stat.; Wayne Hanna - Tifton, GA

Denver Botanical Gardens; Gayle Weinstein - Denver, CO

Farmers Marketing; Bob Arhing, Dick Cooley - Enid, OK: A large scale breeding study was initiated this year by Dr. Robert Arhing to develop a seeded buffalograss variety. Oklahoma was chosen for the study because climatic conditions are favorable for high seed yield where as the Nebraskan climate promotes ergot which reduces seed yield and germinations rates.

The study was designed to control natural pollination of a females by selected males. This was accomplished by randomly planting female and male clones in a block and separating the blocks by an alternative crop to prevent contamination during pollination. A total of 19 females and 7 males are being tested.

Field Club Golf Courses; Tom Baker - Omaha, NE

Lochland Country Club; Craig Furgeson - Hastings, NE

Lofts Seed, Inc: Full Circle, Inc.; Jim Steinke - Madras, OR

Bluestem Seed Co.; George Gates - Prairie Village, KS

O.M. Scotts; Ralph Sanders - Cleveland, TX

O.M. Scott; Virgil Meier - Marysville, OH

3. North Central Region Research (NCR-10) Sites

The North Central Region Research Committee (NCR-10) was established in 1967 to coordinate and promote information exchange between researchers in the midwest. During the 1987 annual meeting, a Regional Alternative Turfgrass Species Trial was initiated with two selections of buffalograss (Texoka and NE 84-315) included in the study. This study was designed to observe several native grasses under low maintenance practices. Replicated plots are 3 ft x 10 ft and divided in half to accommodate a mowing at 2.5 inches and a no mowing treatment. Information about the study will be processed by Dr. Nick Christians (project leader) on a yearly basis.

Iowa State Univ; Nick Christians - Ames, IA
Univ. of Illinois; David Wehner - Urbana, IL
Purdue Univ.; Clark Throssell - West Lafayette, IN
Kansas State Univ.; Jeff Nus - Manhatten, KS
Univ. of Michigan; Bruce Branham - East Lansing, MI
Univ. of Minnesota; Donald White - St. Paul, MN
Univ. of Nebraska; Terry Riordan - Lincoln, NE
Ohio State Univ.; Karl Danneberger - Columbus, OH
Univ. of Wisconsin; Robert Newman - Madison, WI

4. USGA Sites

This study is being initiated to evaluate buffalograss under fairway maintenance and cultural practices in several geographical locations. A preliminary study conducted at the John Seaton

Anderson Turfgrass Facility indicated that buffalograss performed well under low fairway mowing heights (Section V-E). This study includes Texoka and 5 Nebraska selections shown to have superior turf-type quality. Cooperators have agreed to follow a maintenance schedule to include fertilization, irrigation, mowing (fairway height) and pesticide application. Data collection will be taken on a frequent basis with canopy density, turf color and quality, percent greenup and dormancy, internode length, sex and number of inflorescence as parameters to be measured.

Cornell Univ.; Norman Hummel - Ithaca, NY
Southern Illinois Univ.; Ken Diesburg - Carbondale, IL
Univ. of Arizona; Charles Mancino - Tucson, AZ
Oklahoma State; Joel Barber - Stillwater, OK
Colorado State Univ.; Robin Cuany - Fort Collins, CO
Texas A & M Univ.; Garald Horst - El Paso, TX
Iowa State Univ.; Nick Christians - Ames, IA
Univ. of California; Vic Gibeault - Riverside, CA

III. BUFFALOGRASS PLANT BREEDING RESEARCH

A. BUFFALOGRASS FEMALE/MALE SEX RATIO

Three thousand individual buffalograss progeny have been evaluated during the summers of 1988 and 1989 for the following characteristics: color, turf quality, diameter, verdure, stolon number, vertical elongation, number of roots per stolon node, sex expression, and uniformity and smoothness. The caryopses for this study were harvested from ten improved female lines and established individually. The identification of female lines with progeny exhibiting outstanding turf characteristics are expected to indicate superior female parents to be used in developing improved turf-type buffalograss cultivars or a hybrid.

The dioecious nature of buffalograss and the superior turf quality of female plants necessitates the determination of the ratio of sex expression within each line to facilitate the production of predominantly female lines. The heritability of high quality turf characteristics will also be investigated and correlations determined between improved turf characteristics and female sex expression. Selections will be made from the 3000 plants in an effort to further improve buffalograss for the various turf characteristics.

B. DEVELOPMENT OF A DROUGHT RESISTANT SEEDED-TYPE BUFFALOGRASS CULTIVAR WITH IMPROVED TURF QUALITY

This project utilizes screening techniques for evaluating drought resistance differences among several genotypes. Initial screening, by digital image analysis, will be done in the greenhouse using rooting columns to test root elongation and subsequent rooting characteristics. In addition, there will be a male pollination study initiated for selection of male parents used in crossing blocks. Selections of male and female plants will be completed by March 1990 and replicated into an open-pollinated crossing block at Mead, Nebraska. Further evaluation includes progeny testing of the open-pollinated crossing block. Selection will be based on drought resistance and quality characteristics of turfgrass. Success will be determined by heritability estimates and overall performance of synthetic progeny.

C. BUFFALOGRASS BIOTECHNOLOGY

After a great deal of preliminary experimentation a breakthrough has been made on the buffalograss biotechnology project. Callus has been initiated from stolon tips of the female cultivars NE 84-609, NE 85-378 and NE 84-315. This is an important discovery for four reasons: (1) these three cultivars are projected as being patented in the early 1990's; (2) the explant utilized is clonal material; (3) stolon tips are easily handled and can be grown in an unlimited supply in the greenhouse; and (4) callus is being induced from the aesthetically pleasing female plant. Hence, it is possible that large scale commercial production of female artificial seeds via somatic embryogenesis could become a practical reality. Other explants which include the male and female immature inflorescence, immature leaf and mature seed have been utilized, but limited or no success has been found. Current problems that need to be overcome are: (1) callus growth rate is extremely slow and (2) quality of regeneration from callus is poor. However, a list of solutions has been devised, and experiments are underway to heighten the quality of the response.

D. SYNTHETIC PLANTING

In 1987, a synthetic breeding area was established to naturally cross pollinate outstanding male and female buffalograss selections. The resulting seed was harvested and cleaned in 1988. Individual caryopses were germinated and planted into progeny rows (lines) during the 1989 season. The individual plants of each line should exhibit both desirable and undesirable characteristics of the parent plants. This process allows the selection of plant material for desirable phenotypic traits, single crosses and polycrosses used in further studies of buffalograss breeding improvement. As of October 1, all 466 plants of the 52 lines had survived with many of the plants covering the plot (3 ft x 3 ft).

Another method of studying the synthetics is to plant turf plots of each line; however, due to low caryopsis numbers and germination rates of the 1988 seed brought on by the dry and hot summer, this could not be accomplished.

E. BREEDING BLOCKS

A new synthetic planting was established in 1989 to further buffalograss breeding evaluation and develop an F1 seeded variety. An outstanding female selection (7 total) was planted into a block with two of six desirable male selections surrounding it. Each block is separated with tall fescue alleyways to prevent contamination during pollination. The seed will be harvested in 1990 and planted into progeny rows to be further evaluated for F1 variety characteristics. This study is in conjunction with a larger study conducted by Dr. Robert Arhing (Section II-B-2.).

IV. VEGETATIVE ESTABLISHMENT

A. TURF-TYPE BUFFALOGRASS FERTILIZER AND ESTABLISHMENT EVALUATION

Environmental concerns by the public have prompted fertilizer manufacturers to market "organic" fertilizers for residential and commercial use. These fertilizers have lower nitrogen levels and are thought to be safer for the environment. The objective of this study is to compare a standard turf starter fertilizer with one of the new organic products for effectiveness in establishing buffalograss [*Buchloe dactyloides* (Nutt.) Engelm.].

There were 3 phases within the project using the following products: Scott's starter Fertilizer (18-24-3) and the organic product Ringer Upstart (5-10-3) with application at levels of .5, 1, and 2 pounds of N/1,000 ft^2. Phase I was performed in the greenhouse using an equal number of prerooted and non prerooted plugs of buffalograss. The 2 in^2 plugs were planted in 6" pots with 1 plug per pot. The treatments and check were applied randomly in equal replications. The parameters measured were stolon length, stolon number, color, cover, and quality.

Phases II and III of the project were performed at the John Seaton Anderson Turfgrass Facility at Mead, Nebraska. Phase II was similar to Phase I with the prerooted and non prerooted plugs planted in 5 ft. x 5 ft. plots with 14 plots per block and 4 blocks. The parameters measured were stolon number, color, cover, and quality.

Phase III compared fertilizer application methods of soil surface point source. Levels of N used for soil surface application including .5, 1, 2, 4, and 8 lbs. of N/1,000 ft^2 . The higher levels, 4 lbs. and 8 lbs., were applied directly in the planting hole. The plots were 5 ft. x 5 ft. with 11 treatments per block and 4 blocks. Only prerooted plugs were used in this experiment. The parameters measured were the same as those for Phase II.

In all three phases, the verdure, stolons, and roots were assayed for total nonstructural carbohydrates using a modified Weinman method. Total non-structural carbohydrates are a good indication of carbohydrate reserves. It is theorized that as buffalograss emerges from dormancy and uses the reserves, the starter fertilizer will replenish these reserves thus allowing faster establishment. Another area of investigation was whether one type of starter fertilizer replenished the reserves better than the other type.

The data from these experiments is being analyzed to detect any differences in the 2 starter fertilizers. These experiments will be repeated next year.

B. IMPROVED ESTABLISHMENT METHODS

A study was initiated in 1988 which evaluates on the various methods of vegetatively establishing buffalograss: prerooted and non prerooted plugs, sprigging and stolonization. Previous studies established that prerooted plugs established faster than non prerooted plugs; however, they required extensive manual labor and greenhouse space. Because buffalograss is a stoloniferous plant, the study of establishment of plants by stolons was initiated. Two methods of planting stolons was used. The first method (sprigging) required stolons to be planted, at the node, and covered by soil. Sprigging required less manual labor than the plugging method. The second method (stolonization) required a set number of stolons to be scattered evenly in the plot on the surface of the soil. A cultipacker (roller with small nobs) was used to firm the stolons into the surface of the soil. This method required less manual labor than sprigging. Both methods required no greenhouse space as the stolons were harvested directly from the field plants prior to planting in the study.

Initial percent survival and stolon tack down data was taken 4 weeks after establishment. Prerooted and non prerooted plugs and sprigs had 100% survival of all plant material while the scattered stolon method survival was 45%. All treatments had stolon growth with tack down of stolons well established. At the end of the 1989 season all plots exhibited full coverage.

V. CULTURAL PRACTICES

A. ADVANCED EVALUATION AREAS

Advanced evaluation areas are designed to study turf-type quality clones under cultural practices in order to select superior clones for further studies in breeding. At present there are over 150 clones in the 1986, 1987 and 1989 advanced evaluation areas under study with 10 of these clones exhibiting superior turf quality ratings. Cultural practices include mowing at 2.5 inches once a week with clippings removed; fertilizer applied early June, late July and late August at 1 lb. N/1000 ft^2; irrigation applied every 3-4 weeks at 1 inch/application; preemergence weed control applied early spring; and postemergence weed control applied as needed. Data obtained from the areas include: turf color, turf quality, percent greenup in spring, percent dormancy in fall, percent brown appearance of turf during growing season, presence of purple leaves, percent plot cover, internode length, sex, number of inflorescence/ft^2, canopy density, and female inflorescence growth habit (upright vs low growing).

Data from 1988 show the clone NE 84-609 performing well throughout the whole growing season. The selection NE 84-315 performed well in the spring and early summer; however, it declined in late summer and fall. This could be attributed to the mealy bug infestation which will be discussed by Dr. Fred Baxendale in Section V-G-1. The selections NE 84-304 and NE 84-409 were not winter hardy and went into the 1988 season with very low percent cover in plots. These clones exhibited the same characteristics during the 1989 season. Data for the 1989 season is being analyzed.

B. BUFFALOGRASS WATER USE RATES

Two common varieties of buffalograss and four experimental varieties have been evaluated during the summers of 1988 and 1989 to determine buffalograss water use rates. A completely randomized experimental design was set up using the following varieties: Holmes, Texoka, NE 84-315, NE 84-409, NE 84-609 and NE 84-304. A lysimetry research area was established in a field of existing Texoka buffalograss.

Preliminary results show experimental varieties NE 84-315 and NE 84-409 along with the common variety Holmes exhibited the lowest 48-hour water use rates at 10.33, 11.37 and 11.76 mm, respectively. Varieties NE 84-304, NE 84-609 and Texoka showed relatively higher 48-hour rates at 11.89, 12.61 and 12.62 mm, respectively. All the varieties tested show a substantial water savings compared to the most commonly used turfgrasses which have water use rates ranging from 12 to over 20 mm per 48-hour cycle.

C. FERTILIZER RATE AND APPLICATION STUDIES

1. 1988 Fertilizer Rate and Application Sequence Study

This study was initiated in 1988 to evaluate several nitrogen rates and times of application on buffalograss growth and competitive response. A monostand of Texoka was used with two 4 inch plugs of Touchdown Kentucky bluegrass transplanted into the plots. Application rates of nitrogen range from 1 lb. applied at one time to 3 lbs. applied once, twice and three times throughout the growing season. Application dates were from May to October. Maintenance on plots consisted of mowing once a week at 2.5 inches with clippings removed, irrigation applied at 1 inch every 3-4 weeks, preemergent weed control applied in early spring and postemergent control applied as needed. The 1988 planting of the bluegrass plugs was not successful; therefore, new plugs were installed during the 1989 season, however fertilizer applications were continued throughout the 1988 and 1989 season. Data collection will be initiated in 1990 with the following parameters measured: percent spring greenup, percent fall dormancy, percent plot density, turf color and quality, weed species frequency and lateral spread of Kentucky bluegrass.

2. 1988 Fall/Spring Fertilizer Application Study

Initiated in 1988, this study evaluated buffalograss growth and performance response to fall and spring applications of 1 lb. nitrogen/1000 ft^2. Application times began in April and ended in December. This study used a monostand of Texoka with two 4 inch plugs of Touchdown Kentucky bluegrass transplanted into the plots. Maintenance on plots consisted of mowing once a week at 2.5 inches with clippings removed, irrigation applied at 1 inch every 3-4 weeks, preemergent weed control applied in early spring and postemergent control applied as needed. The 1988 planting of the bluegrass plugs was not successful; therefore, new plugs were installed during the 1989 season, however fertilizer applications were continued throughout the 1988 and 1989 season. Data collection will be initiated in 1990 with the following parameters measured: percent spring greenup, percent fall dormancy, percent plot density, turf color and quality, weed species frequency and lateral spread of Kentucky bluegrass.

D. IMAGE ANALYSIS

1. Remote Sensing and Digital Image Analysis for Root Measurements

Research involving the root/soil biosystem, traditionally labor intensive and destructive in nature, is simplified with computer technology. Acquiring rooting data in situ from rhizotron cells entailed manual tracing of roots on gridded acetate sheets and counting the number of roots intersecting the grids. The application of remote sensing and digital image techniques to determine rooting measurements automates the process of data collection and analysis thereby decreasing operator error and time input and increasing accuracy. Studies were initiated using both the manual tracing and digital image method to obtain the following objectives: (1) compare root area measurements using both techniques and (2) determine variability of technique and operator input in root area measurements.

Buffalograss [*Buchloe dactyloides* (Nutt.) Engelm.], vegetatively established in deep mini rooting cells, was used to study rooting parameters. Cells were built of CCA (copper chromated arsenate) treated wood and were 1 ft^2 at the top, .25 ft^2 at the bottom and 4 ft in depth. Front viewing glass was 1/8 in thick ultraviolet transmitting plexiglass installed at 13 degrees from vertical. Plants were established 60 days prior to data collection.

Study 1: Comparison of the manual and computer methods - The manual tracing technique was accomplished by placing a 5 cm^2 gridded acetate sheet on the plexiglass surface and tracing the roots. The grids on the sheet were 1 mm^2. The root area measurement was accomplished by multiplying root lengths by the average root diameter. Average root diameter was obtained by measuring roots harvested from boxes. Roots were measured using a micrometer accurate to .1 mm.

The computer aided technique utilized black and white infrared negatives of the thirty-5 cm^2 areas. Photographic negatives were video digitized using a high resolution video camera. The digitized root images were analyzed using ERDAS (Earth Resources Data Analysis System) image processing software. Spectral pattern recognition analysis was performed on images using a 2 pass unsupervised classification algorithm called "clustering". The groupings resulting from the classification were visually interpreted by operator. The percent root area value was calculated by software. Standardization of techniques was accomplished by using wire of known length and diameter and processing the wire through both the manual tracing and digital analysis methods.

Linear regression analyses were performed to determine the relationship between: (1) image analysis and manual tracing and (2) estimated and actual percent root area. Results from both analyses showed high correlation and linear relationships ($PR>F = 0.0001$) between variables indicating the computer method was as accurate as the manual tracing method. Technique efficiency was indicated by operator time and manual labor input. Processing of a manually traced image was 30 minutes compared to computer generated image processing of 15 minutes.

Study 2: Determination of variability between technique and operator input - Images of roots and wire were analyzed by 8 operators using the manual tracing and image analysis techniques, described in Study 1. The operators were of various computer and science backgrounds; however, they were instructed in the same class (2-hour period) with demonstrations and individual computer practice. A step-by-step handbook was developed to aid operators on computer and manual tracing processing techniques. Operators processed all images individually with author present to answer any questions on technical (computer) processes. Subjective questions (root vs non root determination) had to be addressed by the operator based on their previous knowledge from class instruction and the handbook.

The study analyzed the effect of operators on the percent root area values using the two techniques. The experiment was split plot design with technique (tracing and image analysis) as the main factor and operator as the subfactor. Analysis of the relationship between the different operators and technique indicated technique as highly significant. The subfactor of operator was not significant indicating that the variance between operators does not make a difference for the percent root values. With proper instruction on methods, varying operators can process images without impairing the accuracy of calculated values. Interaction between technique and operator was not significant indicating that within the technique the operators did not vary in percent root area calculations. Further comparison of the interaction between technique and operator and the actual values will be studied.

The method of remote sensing and digital image analysis is an efficient and accurate technique for determining percent root area measurements. Manual tracing and digital image processing were highly correrlated with time and manual input by operator was reduced by 50% with the computer method. Processing of digital images by different operators was possible without loss of accuracy. The application of remote sensing and digital image techniques to determine root measurements automates the process of data collection and analysis thereby decreasing processing time and increasing accuracy.

2. Evaluation of Buffalograss Selections for Rooting Differences

The potential of buffalograss to be used as a turfgrass in areas of low moisture has been substantiated by many studies. Studies further indicated that water use rates of buffalograss, however widely varied, are considerably less than other commonly used turfgrasses. Rooting distribution differences have been linked with the variation of water use rates between cultivars. A study utilizing the deep mini rooting cells and improved buffalograss cultivars was established in the greenhouse with the objective of determining and comparing rooting differences and correlating these values with water use rates.

The study contained 6 Nebraska selections (NE 84-315, NE 84-304, NE 84-609, NE 84-409, NE 85-378 and NE 85-5009) and Texoka replicated 4 times in a randomized complete block design. Plants were established 75 days before rooting measurements were obtained using the manual tracing and computer methods as outlined in Section V-D-1. Three rooting images were obtained from the cells at 4, 12 and 20 inch depths. Analysis of data is under way with preliminary results showing differences in cultivar root distribution.

E. FAIRWAY MANAGEMENT STUDY

Buffalograss, because of its low maintenance requirements, is well suited for use in rough areas. Observation of research plots since 1985 suggests that buffalograss could be used on golf course fairways with significant savings of water, fertilizer, pesticides and mowing. Results from studies indicated a savings of greater than 50% for water and fertilizer use. A study was initiated to evaluate buffalograss turfgrass quality and performance under modified fairway maintenance schedules and playing conditions.

The experimental fairway area consisted of over 2000 Texoka, Sharp's Improved and Nebraska experimental selections planted in 1985 on 3 ft. centers. Area maintenance prior to fairway study initiation included: 2 lb. N/1000 ft^2/growing season, a 2.5 inch mowing height and infrequent irrigation.

The design of the study was split plot, replicated 6 times , with fertilizer treatments as main factor and traffic application as the subfactor. Fertilizer treatments were applied to whole plots as follows: 0, 1, 2 and 3 lb. N/1000 ft^2. Plots were divided in half with one half receiving a traffic treatment of 5 passes using a modified traffic simulator built at the university.

Management during the 1989 growing season included: mowing at 2.5 inches with rotary mower, aerification with core aerator, vertical tilling to level area, and fertilizer and wear treatments. Beginning in August an irrigation system was installed; therefore, wear treatments ceased. Fertilizer treatments were applied throughout the season. Cultural practices for the 1990 growing season will include: mowing at 5/8 inch with reel mower, aerification, rolling to further level area, irrigation to maintain active growth and fertilization and wear treatments.

Study was evaluated for overall turfgrass quality and canopy temperature and density during the 1989 season. Evaluation of plots during the 1990 season will include overall turfgrass quality, canopy temperature and density, playing conditions (ball roll-stimpmeter, divot recuperation), rooting density and soil compaction (penetrometer).

Preliminary statistical results indicated no significant difference for fertilizer treatment in 1989; however, traffic vs non traffic treatments were significant for the entire season. Areas with greater soil surface area (traffic plots) had increased stolon activity, thus accounting for differences in shoot counts and verdure weights. With greater numbers of actively growing stolons, senescing material is lessened, resulting in lower trafficked canopy temperature readings. Frequent mowing at low heights did not affect the overall quality of turf; however, there were variations for tolerance to mowing among the selections indicating further study is needed.

In summary, buffalograss, when actively growing, has the potential to tolerate fairway mowing heights and wear treatments comparable to Kentucky bluegrass. Nitrogen level, during 1989, did not have an effect on turfgrass quality, wear tolerance, verdure or leaf temperatures; however, continued testing is needed to determine further potential of buffalograss for golf course fairway use.

F. MECHANICAL TURF PLUGGER FOR BUFFALOGRASS

A mechanical turf plugger was developed by retrofitting a Ryan GA 30 aerator with plugging tines. Plugging is a vegetative propagation method used with turfgrasses that have strong stoloniferous or rhizomatous growth habits. The mechanical turf plugger was evaluated under field conditions to determine the adaptation of this method of plugging for extracting Buffalograss [*Buchloe dactyloides* (Nutt.) Engelm.] plugs.

Four plug tine designs were evaluated in three levels of soil moisture content. Test results indicate the performance of the plugging machine is significantly dependent on these two factors (Figure 1). The contrast in performance of the tines exhibits the importance of the tine design. Variation in performance due to soil moisture suggests that there is an optimum range of operation. The underlying element is the soil-metal friction produced. Sufficient soil-metal friction must be produced to overcome the tensile strength of the soil and roots to successfully extract the turf plug. The plug tine design and soil moisture impact the resulting friction force.

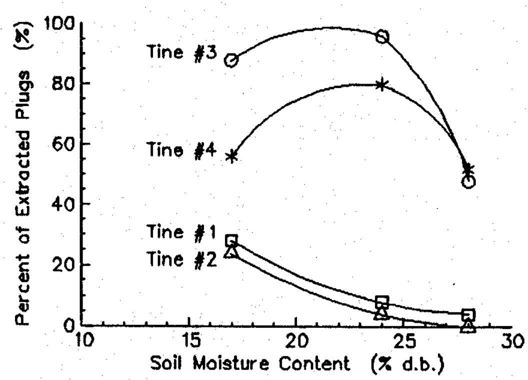
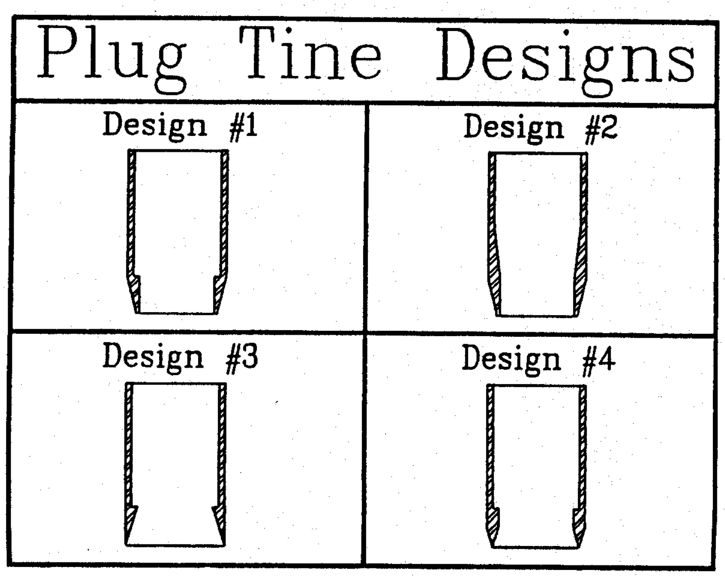


Figure 1. Plug tine performance in three levels of soil moisture. Experimental material: Buffalograss in Sharpsburg silty clay loam soil.

Preliminary analysis of the data suggest that plug tine #3 performs better then the other three tines. The optimum performance of tine #3 occurs between 18-25% soil moisture. In this moisture range, tine #3 extracted greater than 90% of the turf plugs.

The preliminary analysis of the data suggest that mechanical plugging of Buffalograss is possible with the Ryan GA 30 aerator retrofitted with plugging tines.



G. BUFFALOGRASS INSECT STUDIES

1. Buffalograss Insect Update

Over the last several years, turfgrass researchers have placed considerable emphasis on the development of energy efficient turfgrass species requiring less water, fertilization and mowing than conventional varieties. This effort has been driven in part by a nationwide emphasis on water and energy conservation and on environmental and groundwater concerns. Buffalograss [*Buchloe dactyloides* (Nutt.) Engelm.] is a warm season grass which offers excellent heat and drought tolerance and performs well under low maintenance regimes. At the present time, however, few of the existing buffalograss varieties meet acceptable turfgrass quality standards. At the University of Nebraska, a major buffalograss program is underway to develop improved turf-type buffalograss varieties, identify optimal cultural practices and obtain information on the identification and management of potentially serious plant diseases, weeds and insect pests.

Little is known concerning the insects and mites associated with buffalograss. Only a few arthropods have been reported feeding on buffalograss and even fewer have been shown to cause significant damage. The earliest reference of insect injury to buffalograss was in 1940 when white grubs were observed damaging buffalograss stands in Texas. Later reports of buffalograss-feeding arthropods included the buffalograss webworm, grasshoppers, leafhoppers, mound-building prairie ants, Rhodesgrass scales and a false spider mite which was thought to cause witches' broom-type symptoms. In 1989, chinch bugs were observed causing extensive damage to buffalograss lawns at several locations in Nebraska.

In 1988, research was initiated at the John Seaton Anderson Turfgrass Facility, located at Mead, Nebraska, to document the insects and mites affecting buffalograss in Nebraska. This project has been designed to identify potential pests of buffalograss and to evaluate their damage potential. Throughout this study, special attention will be given to the identification of predators, parasites and other potentially important natural enemies which may play a role in the regulation of pest populations. High priority will be placed on the development of management recommendations for the insects and mites identified as pests of buffalograss. Accordingly, studies involving damage threshold levels, cultural practices, predator/prey interactions, host plant resistance, sampling techniques and the development of efficient pest monitoring systems will be emphasized. As part of this effort, chemical controls will be evaluated for efficacy against selected buffalograss pests. The ultimate goal will be to develop integrated management strategies for the major arthropod pests of buffalograss in Nebraska.

The need to establish a buffalograss insect research program first become evident when turfgrass researchers began noticing a gradual decline in the overall quality in many of their buffalograss variety plots. This condition was characterized by a general thinning and browning of affected varieties beginning in mid to late summer. Samples were collected from affected buffalograss plots and returned to the laboratory where subsequent examination revealed the presence of numerous mealybugs. A sample of these mealybugs was sent to USDA-APHIS where they were identified as *Tridiscus sporoboli* and *Trionymus* sp. A notation accompanying the *Trionymus* sp. determination indicated that there were no comparable identified specimens of this species in the U. S. National Collection.

Additional buffalograss samples were obtained from other locations in Nebraska (Lancaster, Saunders, Nuckolls, Lincoln and Dawes counties) and these were also found to harbor mealybug infestations. While most buffalograss samples contained relatively few mealybugs (2-25), a few had in excess of 2500 mealybugs per 1/4 sq. ft. section of turf. Mealybugs have also been found in samples of Kentucky bluegrass, tall fescue, perennial ryegrass and bromegrass collected from turf areas located near buffalograss stands. This suggests that mealybugs may already have been present in these grasses and moved to buffalograss or, conversely, that the mealybugs moved from the buffalograss to surrounding grasses.

Buffalograss mealybugs are dark pink to purple-gray in color and are covered with a white, waxy secretion. Specimens range in size from less than 0.2 mm for the smallest nymphs to nearly 3.0 mm for adult females. Clusters of pale pink eggs are deposited under leaf sheaths within a cottony mass. Adult males are characterized by a single pair of wings on the mesothorax and three pairs of eyes.

Mealybug injury to buffalograss appears as a general yellowing or browning of the foliage similar to the symptoms experienced during periods of drought stress. In severe cases, plants turn straw-brown and may eventually die. Infested plants typically have an area of reddish or purple discoloration, along with considerable fibrous debris in the vicinity of mealybug feeding. Mealybugs are most commonly found behind the leaf axils enclosing the pistillate spikelets or behind leaf sheaths in the crowns or nodes of plants.

At the present time, studies are underway at the John Seaton Anderson Turfgrass Facility to secure a better understanding of mealybug biology, ecology, geographic distribution, seasonal abundance and injury potential in buffalograss.

2. Control of Chinch Bugs in Buffalograss

A chinch bug study was conducted on a buffalograss lawn in Lincoln, Nebraska. Insecticides were applied on 6 Sept to 5 x 5 ft plots arranged in a random complete block design and replicated 4 times. Topography in the treated area was level. The predominant grass species was buffalograss [*Buchloe dactyloides* (Nutt.) Engelm.] (98%) which was maintained at a mowing height of 5.0 inches. Conditions at the time of application were as follows: air temperature--78°F; soil temperature (4 inch depth)--72°F; soil type--silty clay loam; soil moisture--well below field capacity. Insecticides were applied with a CO_2 sprayer using a LF-4 nozzle at 24 psi and delivering 4 or 10 gal. finished spray per 1000 ft^2. A total of 4.79 inches of rainfall occurred during the post-treatment period. No irrigated water was applied. Product efficacy was evaluated 5 day after treatment (Sept. 11) by cutting from each plot 4 randomly selected sections of turf to a depth of 2 inches with a 4-inch cup cutter (0.35 ft^2 total area per plot). Turf sections were returned to the laboratory and placed in Berlese funnels. Extracted chinch bugs [*Blissus leucopterus leucopterus*] were counted after 48 hours.

Pretreatment counts indicated an average of 30-35 chinch bug nymphs and adults/0.35 ft^2 in the test area. At 5 day after treatment, Talstar 10WP (4 and 10 gal finished spray/1000 ft^2) and Dragnet FT (10 gal. finished spray/1000 ft^2) had provided greater than 90% reduction in chinch bug numbers. Heavy rainfall (4.79 inches) during the post-treatment period may have influenced the results of this study. No phytotoxicity was observed.

Treatment	Rate 1b(AI)/Acre	Finished Spray gal/1000ft^2	Mean Chinch Bugs/ 0.35ft^2 5 DAT	% Reduction
Talstar 10WP	0.2	10.0	0.8b	97.4
Talstar 10WP	0.2	4.0	1.8b	94.1
Dragnet FT	0.44	10.0	2.8b	90.8
Cynoff WP	0.35	4.0	7.5b	75.2
Tempo 2	0.1	4.0	7.8b	74.3
XRM-4964 50WG	1.0	4.0	9.5b	68.6
Sevin SL	8.0	4.0	13.8ab	54.5
Dragnet FT	0.44	4.0	15.0ab	50.5
Cynoff WP	0.35	10.0	18.8ab	38.0
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Means in a column followed by the same letter are not significantly different (P=0.05; DMRT).

II. BUFFALOGRASS WEED CONTROL

An experiment was established during 1989 to evaluate herbicide tolerance in buffalograss turf with postemergence crabgrass material. Herbicides evaluated included: MON-15100, Fenoxyprop, BAS-514 and Primisulfuron. Treatments were applied July 17 in 3 rates (1/2x, 1x and 2x). Fenoxyprop was the only herbicide to cause injury to turfgrass while all other materials demonstrated excellent buffalograss tolerance at all rates. Results suggest that several of the newer products under development have potential for use in buffalograss.

VI. COMMERCIALIZATION OF IMPROVED BUFFALOGRASS

A. GRASSES DUE TO BE COMMERCIALIZED

After reviewing all results from 1988 and 1989, it has been determined that three experimental genotypes should be released and commercialized. The Number 1 genotype throughout the country and in our research plots at the University of Nebraska is NE 84-609. This buffalograss is a southern type with good adaptation in the south and potential adaptation in the basic north. However, we are concerned that NE 84-609 may not have sufficient cold hardiness to be initially released in the northern portion of the United States. At this time, it is not felt that adequate information is available to release NE 84-609 for use in the north, which includes states such as Nebraska and Colorado. To date, however, NE 84-609 has performed well in Nebraska and in Ohio, but one more year will provide additional information to determine cold hardiness. We are proceeding with developing a crop registration, a plant patent, and release of NE 84-609 for use in the southern United States. The other two experimental genotypes, NE 85-378 and NE 84-315, are northern adapted buffalograsses and should have no problem with performance in the basic north. In addition, these grasses have performed well in the southern United States. Therefore, it is anticipated that these grasses would be released nationally with initial use in the basic north. Currently, plant patent and crop registrations are being prepared for each of these grasses. It was thought that this would be completed by now, but with the unexpected retirement of Ed Kinbacher and the change in responsibilities of Bob Shearman, this process has been delayed. It is hoped that within the next month, the release for NE 84-609 will be completed with the crop registration and plant patent prepared.

B. COMMERCIALIZATION--SEEDED BUFFALOGRASS

An agreement has been received from a consortium of companies which includes Farmers Marketing Corporation, Yuma, Arizona; Arrow Seed, Broken Bow, Nebraska; and Johnston Seed, Enid, Oklahoma. This agreement calls for the development of a new seeded turf-type buffalograss using plant material from the University of Nebraska. The agreement calls for them to make a research payment to Nebraska for three years and to obtain rights to a seeded buffalograss developed out of this agreement. This agreement has been reviewed by the University of Nebraska and the United States Golf Association. At the present time, the agreement is being reviewed by parties at the University of Nebraska to determine modifications of the major concerns. Currently, the research work is being carried out under a screening agreement with the Farmers Marketing Corporation with the understanding that it will take several years to develop a new cultivar. It is hoped that an agreement can be reached that will be mutually acceptable to all parties involved in the development of these new grasses.

C. COMMERCIALIZATION--VEGETATIVE BUFFALOGRASS

To date, we have not encouraged agreements on vegetative buffalograsses. We have received inquiries from several companies who have displayed interest in marketing a vegetative buffalograss in the basic north section of the United States. It was felt that it would be best to wait until a crop registration and plant patent have been received before discussing the possibility of having a proprietary grass for an individual company. However, we have been contacted by Crenshaw/Douget, Inc., who has an interest in NE 84-609 for use in the Texas market. It is believed that an agreement will be received shortly from this company that may be worthy of consideration. One of the principles in this group, David Douget, is a Texas sod producer with good credentials and a strong interest in buffalograss. The second individual is Ben Crenshaw, who is involved in building golf courses in Texas and has an interest in using buffalograsses such as Prairie or NE 84-609 in the rough part of the golf course. Even if an agreement is not forthcoming, it is felt that it would be worthwhile to work with this company to at least have an area of evaluation of NE 84-609 in comparison with Prairie buffalograss.

D. Commercial Testing/Evaluation

During 1990, the University of Nebraska will work with golf courses and sod producers in evaluating the performance and potential of vegetative buffalograsses in various locations. It will be our effort to make these planned releases available under agreement to individuals who would have the most positive effect on our project. We will be working with the United States Golf Association and the Golf Course Superintendents Association of America on this portion of the project.

VII. PRESENTATIONS

Posters

Riordan, T.P., R.C. Shearman, S.A. deShazer, and E.J. Kinbacher. Evaluation of turf-type buffalograsses for golf course fairway use. American Society of Agronomy meetings. October 1989.

Royes, S.D., and T.P. Riordan. Evaluation of hybridization methods for turf-type buffalograss. American Society of Agronomy meetings. October 1989.

deShazer, S.A., T.P. Riordan, R.C. Shearman, and D.C. Rundquist. Digital image technique for determination of root measurement. American Society of Agronomy meetings. October 1989.

Schwarze, D.J., T.P. Riordan, E.J. Kinbacher, and R.C. Shearman. Development of *Buchloe dactyloides* (Nutt.) Engelm. for turf use. American Society for Horticultural Science. 1989.

Papers

Schwarze, D.J., T.P. Riordan, E.J. Kinbacher, and R.C. Shearman. Total non-structural carbohydrate analysis of prerooted and non prerooted vegetative buffalograss plugs. American Society of Agronomy meetings. October 1989.

Browning, S.J., S.A. deShazer, T.P. Riordan, E.J. Kinbacher, and R.C. Shearman. Buffalograss sex expression and correlations with turf-type characteristics. American Society of Agronomy meetings. October 1989.

Presentations

Klingenberg, J.P. and T.P. Riordan. Turfgrass Water Management Research at UNL. 3rd Annual Water Policy Forum. October 1989.

Riordan, T.P. The Significance and Contributions of Turfgrass Breeding Programs and Characteristics and Attributes of Buffalograss (Buchloe dydactyloides). Ringer Corporation visit. Minneapolis, Minnesota. June 1989.

Riordan, T.P. Turfgrass Recommendations,South Dakota Turfgrass Conference. Sioux Falls, South Dakota. March 1989.

Shearman, R.C. After the Drought. South Dakota Nurserymen's Conference. February 1989.

Riordan, T.P. Development of Turf-Type Buffalograss-Golf Course Management Techniques: Part II. GCSAA International Conference. Fresno, California. February 1989.

Riordan, T.P. Turfgrass Breeding Research Update. Nebraska Turfgrass Conference. Omaha, Nebraska. January 1989.

Shearman, R.C. Turfgrass Drought Resistance Research Update. Nebraska Turfgrass Conference. Omaha, Nebraska. January 1989.

Shearman, R.C. Fertilization & Preemergence Herbicides Use on Low Maintenance Turf. Nebraska Turfgrass Conference. Omaha, Nebraska. January 1989.

Table 1. Root production at two rooting intervals (0 - 10.16 and 10.16 - 30.48 cm) averaged over mowing heights and vertical mowing frequencies (V.M.) on 5/31 and 8/15/89.

	Root dry weight (mg)			
	May 31		August 15	
Height(cm)	0-10.16cm	10.16-30.48cm	0-10.16cm	10.16-30.48cm
3.2	776.1 NS*	54.3 NS*	445.3 NS*	60.5 NS*
4.0	741.6	52.1	411.0	71.2
4.8	814.1	42.7	471.4	61.5
V.M.				
0	860.9 NS*	46.0 NS*	437.8 NS*	55.2 NS*
14	740.4	55.1	475.6	79.4
28	730.4	48.0	414.3	58.5

* = No significance with alpha = 0.05

Table 2. Soil temperatures extremes and ranges averaged over mowing heights and vertical mowing frequencies (V.M) on 7/9/89.

	Soil Temperatures (°C)		
Height (cm)	Max.	Min.	Range
3.2	31.53 A*	20.90 NS**	10.62 A
4.0	31.39 B	20.83	10.54 A
4.8	31.20 C	20.98	10.23 B
V.M.			
0	31.19 NS	20.98 NS	10.21 NS
14	31.55	20.86	10.69
28	31.37	20.87	10.50

* = Means separated using Duncan's Multiple Range Test at alpha = 0.05
** = No significance with alpha = 0.05

Syringing Study on a Penncross Creeping Bentgrass

Tommy Salaiz and R. C. Shearman

Syringing is commonly practiced on golf greens to alleviate heat stress. A study was initiated in 1988 to evaluate the effects of syringing and its interaction with two Nitrogen and three Potassium fertilization rates.

A split-split-plot design with the Nitrogen rates (15 and 30 g N/M^2/season) as the main plots, Potassium rates (0, 30, and 60 g K/M^2/season) as the subplots, and syringing vs. no syringing as the sub-subplots, was used.

The syringing process involved spraying on 3.3 mm of water at 11:00 am with a fan type nozzle. This process can be modified to include differing amounts of water, timing of application, and type of nozzle used. Hourly canopy temperatures and soil temperatures following syringing were measured.

Only limited data were collected from this study during 1989. A data comparing syringed versus not syringed treatments were collected for soil temperature (Figure 1) and canopy temperature (Table 1). Syringed turfs had lower canopy temperature ranges, but higher soil temperatures than unsyringed turfs. Data for these comparisons were not collected until near the end of the 1989 summer. More data will be collected during 1990 with emphasis being placed on stress days with high and low ET demand.

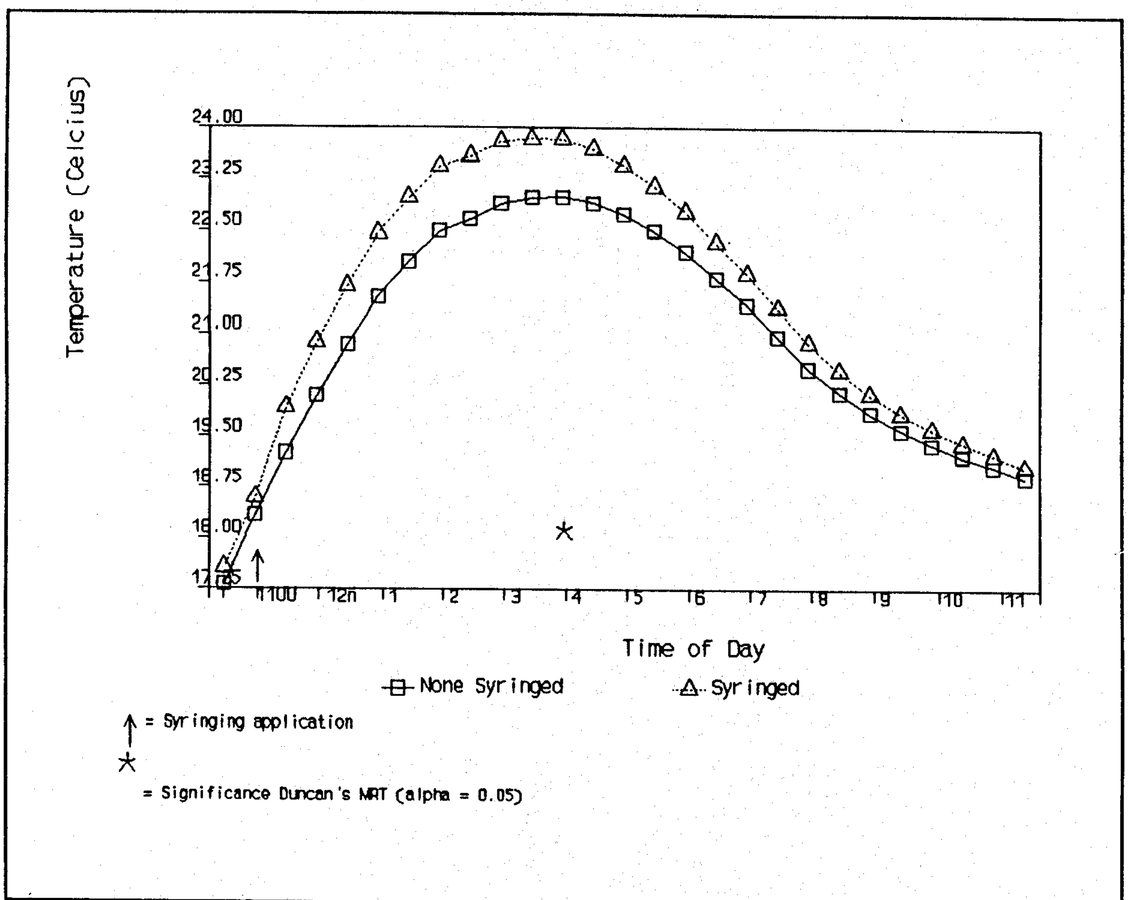

Figure 1. Soil temperatures at one inch soil depth following syringing.

Table 1. Canopy temperatures extremes and ranges averaged over Syringing practices 9/17/89.

Canopy Temperatures (°C)	Max.	Min.	Range
Syringed	27.81 A*	22.52 A	5.3 A
Non-Syringed	28.38 A	22.59 A	5.78 B

* = Significance based on Duncan's MRT with alpha = 0.05.

CREEPING BENTGRASS FAIRWAY MANAGEMENT

Kyoung-Nam Kim and R.C. Shearman

The fairway management study was conducted to determine the effect of irrigation frequency, clipping removal or return, nitrogen nutrition and traffic or no traffic on a Penncross creeping bentgrass competition with annual bluegrass under fairway conditions. A Penncross creeping bentgrass fairway was established from seed in May of 1988 on a Sharsburg silty-clay loam (Typic Argiudoll). The bentgrass was mowed at 12.5mm (0.5inch) four times per week. The turf received 5g P / m^2/ season (1lbs. P / 1000ft^2) and 15g K / m^2 / season (3lbs. K / 1000ft^2). The turf was corecultivated in spring and fall and then a soil topdressing was applied in spring and fall. The soil which contained annual bluegrass seed was obtained from a local golf course. Pesticides were given only as needed. The vertical mowing was applied in fall, 1989.

Treatments were arranged in a split-split plot design with irrigation frequency as main plots, clipping treatments as sub-plots and nitrogen levels as sub-subplots (Table 1). The treatments were replicated 3 times in a completely randomized design. The irrigation replacement was based on ET rates as determined by the Nebraska modified Penman equation. The irrigation schedule using 80% ET rates was changed weekly to light frequent or heavy infrequent application. The clipping treatments were divided into clippings return or clippings removal as using basket. The nitrogen levels were applied at 5, 15 and 25g N / m^2 / season (1, 3 and 5 lbs N / 1000ft^2). The irrigation by clipping by nitrogen treatments were divided so that one-half received traffic and the other did not. Traffic was given twice weekly with the traffic simulator over the trafficked areas until the end of September. The traffic simulator was constructed of a 318 kg (700 lbs.) steel drum inserted with metal golf spikes on 76 mm (3 inch) centers. Traffic versus nontrafficked areas were considered as separate studies. All the treatments were initiated from the late May, 1989.

Treatments were evaluated for turfgrass quality, turfgrass color, fairway playing conditions such as ball roll, divoting tolerance, divot recovery, and load bearing capacity, thatch accumulation, *Poa annua* encroachment, nutrient analysis, and soil bulk density. Data were subjected to analysis of variance and means were seperated, using Least Significant Difference at the 5% probability level.

Turfgrass quality and color: Irrigation frequency differed in turfgrass quality and color rating under trafficked conditions (Tables 2 and 4). The frequent irrigation showed better quality and color than the infrequent irrigation. Nitrogen rates also varied in turfgrass quality and color rating. The rates of 3 and 5 lbs. N per 1000 sq ft per season provided higher rating than 1 lbs N per season. Under nontrafficked conditions, the turfgrass quality and color varied from higher for frequent irrigation to lower for infrequent irrigation (Tables 3 and 5). Nitrogen responses greatly differed by season. Until early July, turf quality and color showed an increase as nitrogen increased from 1 lbs. per 1000 sq ft per season to 5 lbs. per season but they after the middle of July greatly decreased in the level of 5 lbs. N per season rather than that of 1 and 3 lbs. N. Unlike trafficked conditions, there was a irrigation by nitrogen interaction for turfgrass quality. These results demonstrate careful manipulation of fertilization program according to environmental conditions.

Fairway playing condition: Ball roll conditions greatly varied by irrigation frequency, clippings and nitrogen rates (Tables 6 and 7). The responses to fairway speed were the same under both trafficked conditions and nontrafficked conditions. Infrequent irrigation, clippings removal and lower nitrogen rates significantly offered the better playability than frequent irrigation, clippings return and higher nitrogen rates, respectively. There was a irrigation by nitrogen interaction for fairway speed under both areas in September.

Treatments differed in load bearing capacity. Trafficked area had higher load bearing capacity under the infrequent irrigation, clippings removal and lower nitrogen levels rather than the frequent irrigation, clippings return and higher nitrogen levels, respectively (Table 8). In nontrafficked area, high load bearing capacity was also obtained from the infrequent application, clippings removal and lower nitrogen rates (Table 9). A clippings by nitrogen interaction was observed under nontrafficked area in October. High load bearing capacity means high resistance of turfgrass leaves to compression and it is related to the high wear resistance. Thus, high load bearing capacity indicates better playability than low load bearing capacity. This explanation could be identified by the data of fairway speed (Tables 6 and 7). It should be remembered, however, that additional ball speed was always accompanied by a loss of turf quality (Tables 2 and 3). These results indicate that the favorable environments for ideal quality differ from those for better playability.

Divot tolerance: Treatments differed in divot tolerance. The infrequent irrigation was more tolerant to divoting than the frequent irrigation under both trafficked and nontrafficked conditions (Tables 10 and 11). The clippings return showed an increase in divot tolerance under both conditions in comparison with clippings removal. These responses were negatively correlated to soil moisture content when divoting was applied. There was statistically no significance in response of three different nitrogen levels but interactions between irrigation and nitrogen and among irrigation, clippings and nitrogen treatments were observed under only trafficked conditions.

Divot-return (D+) recovery showed statistically no significance among treatments. But both trafficked and nontrafficked area had the same response to D+ recovery that frequent irrigation, clippings return and higher nitrogen rates provided rapidly better recovery than infrequent irrigation, clippings removal and lower nitrogen rates, respectively (Tables 12 and 13).

Divot-removal (D-) recovery also showed no significance by treatments. But some response was observed. Under trafficked area, frequent irrigation, clippings return and lower nitrogen levels gave repidly better recovery than infrequent irrigation, clippings removal and higher nitrogen levels, respectively (Table 14). The lower nitrogen reaction was considered mainly to be caused by less injury to divoting. In nontrafficked area, infrequent irrigation, clippings return and higher nitrogen rates showed better recovery rather than frequent irrigation, clippings removal and low nitrogen rates, respectively (Table 15). The infrequent irrigation response was regarded mainly to be resulted from less injury to divoting. These results indicate that the irrigation program should be well manipulated for less injury and rapid recovery from divoting , especially during high peak time of playing games.

Thatch accumulation: Irrigation frequency and clippings differed in thatch accumulation (Tables 16 and 17). The infrequent irrigation accumulated less thatch than the frequent irrigation. The clippings removal showed less thatch depth than the clippings return. These responses were alike under both trafficked and nontrafficked conditions and especially had the significant difference in August. But the response of nitrogen levels was irregular under both areas. However, interactions between irrigation and nitrogen and among irrigation, clippings and nitrogen were found under trafficked area in August.

Soil bulk density: Treatments varied in soil bulk density (Tables 18 and 19). In July, there was found a significant difference. The infrequent irrigation had less soil bulk density than the frequent irrigation under both trafficked and nontrafficked conditions. As nitrogen levels declined from 5 lbs. to 1 lbs. per 1000 sq ft per season, soil bulk density showed a decrease under both areas. The clippings removal provided less soil bulk density than the clippings return under traffic conditions. There were the irrigation by nitrogen interaction for both areas and the clippings by nitrogen interaction for only nontrafficked area. In September, there was found no significance except clippings response under trafficked conditions. The clippings return had higher soil bulk density than the clippings removal. Until now, all treatments was no problem for turfgrass root growth and development.

Other growth parameters such as Poa annua encroachment and nutrient analysis were included but were not available at this time. For the measurement of annual bluegrass invasion under Penncross creeping bentgrass fairway condition, the plugs of Poa annua var. reptans were transplanted in early October, 1989. The nutrient analysis on soil and leaves has been made in the Soil Testing Center, at the University of Nebraska, Lincoln. This study will be repeated in the 1990 growing season and all the growth parameters this year will be assessed again next year.

Table . Treatments for Pencross creeping bentgrass fairway management study designed by split-split plot.

Treatment No.	Irrigation Frequency	Clippings	Nitrogen Rates (lbs. N / 1000 sq ft / season)
1	1x [z]	C+ [y]	1 [x]
2	1x	C+	3
3	1x	C+	5
4	1x	C-	1
5	1x	C-	3
6	1x	C-	5
7	7x	C+	1
8	7x	C+	3
9	7x	C+	5
10	7x	C-	1
11	7x	C-	3
12	7x	C-	5

z Irrigation frequency : 1x means light , frequent application and 7x means heavy, infrequent application with the same amount of 80 % ETp.

y Clippings: C+ means clippings return and C- clippings removal after mowing.

x Nitrogen rates: 1, 3 and 5 represent 1, 3 and 5 lbs. nitrogen per 1000 sq ft per season.

Table . The quality evaluation of Penncross creeping bentgrass maintained as a fairway turf under trafficked conditions during the 1989 growing season.

	Visual Quality [z]					
Treatment No.	May25	June13	July5	Aug5	Sept6	Mean
1. 1x C+ 1 N	5.3	4.3	5.6	5.0	6.7	5.4
2. 1x C+ 3 N	5.3	5.0	6.0	6.3	7.3	6.0
3. 1x C+ 5 N	5.0	5.0	6.3	6.0	7.3	5.9
4. 1x C- 1 N	5.0	4.3	5.3	5.7	7.0	5.5
5. 1x C- 3 N	5.3	5.3	6.0	6.0	7.7	6.1
6. 1x C- 5 N	5.3	5.7	6.7	6.3	8.3	6.5
7. 7x C+ 1 N	5.3	4.6	5.6	7.3	8.3	6.3
8. 7x C+ 3 N	5.0	4.7	6.3	8.3	8.7	6.6
9. 7x C+ 5 N	5.6	5.3	7.0	8.7	8.7	7.1
10. 7x C- 1 N	5.3	4.7	5.3	7.7	8.7	6.3
11. 7x C- 3 N	5.3	4.7	6.3	8.3	8.3	6.6
12. 7x C- 5 N	5.7	5.7	6.7	8.0	9.0	7.0
Irr. frequency						
1x	5.2	4.9	6.0	5.9b	7.4b	5.9b
7x	5.4	4.9	6.2	8.1a	8.6a	6.6a
LSD(0.05)	ns	ns	ns	0.4	0.5	0.3
Clippings						
C+	5.3	4.8	6.2	7.0	7.8	6.2
C-	5.3	5.1	6.1	7.0	8.2	6.3
LSD(0.05)	ns	ns	ns	ns	ns	ns
N rates						
1	5.3	4.5b	5.5b	6.4b	7.7b	5.9b
3	5.3	4.9ab	6.2a	7.3a	8.0ab	6.3a
5	5.4	5.4a	6.7a	7.3a	8.3a	6.6a
LSD(0.05)	ns	0.6	0.6	0.5	0.6	0.4

z Visual quality was made on a 1-9 scale with 1= poorest quality and 9 = best quality.

Table . The quality evaluation of Penncross creeping bentgrass maintained as a fairway turf under nontrafficked conditions during the 1989 growing season.

	Visual Quality[z]					
Treatment No.	May25	June13	July5	Aug5	Sept6	Mean
1. 1x C+ 1 N	6.7	6.7	6.7	5.7	7.0	6.5
2. 1x C+ 3 N	7.3	7.3	7.0	4.7	6.7	6.6
3. 1x C+ 5 N	7.3	7.7	8.3	4.3	6.3	6.8
4. 1x C- 1 N	6.7	7.0	6.0	5.0	7.0	6.3
5. 1x C- 3 N	7.0	6.7	7.0	4.7	6.3	6.3
6. 1x C- 5 N	7.0	7.7	7.7	4.0	5.3	6.3
7. 7x C+ 1 N	7.0	6.7	6.7	6.3	7.7	6.9
8. 7x C+ 3 N	7.7	7.7	7.7	5.3	6.7	7.0
9. 7x C+ 5 N	7.0	8.3	8.0	4.0	6.3	6.7
10. 7x C- 1 N	7.0	6.3	6.3	6.7	8.0	6.9
11. 7x C- 3 N	6.7	7.3	7.3	6.0	7.7	7.0
12. 7x C- 5 N	6.7	8.0	7.7	4.3	6.3	6.6
Irr. frequency						
1x	7.0	7.2	7.1	4.7b	6.4b	6.5b
7x	7.0	7.4	7.3	5.4a	7.1a	6.8a
LSD(0.05)	ns	ns	ns	0.4	0.4	0.2
Clippings						
C+	7.2a	7.4	7.4a	5.1	6.8	6.8
C-	6.8b	7.2	7.0b	5.1	6.8	6.6
LSD(0.05)	0.3	ns	0.3	ns	ns	ns
N rates						
1	6.8	6.7c	6.4c	5.9a	7.4a	6.7
3	7.2	7.3b	7.3b	5.2b	6.8b	6.7
5	7.0	7.9a	7.9a	4.2c	6.1c	6.6
LSD(0.05)	ns	0.3	0.3	0.5	0.5	ns

z Visual quality was made on a 1-9 scale with 1 = poorest quality and 9 = best quality.

Table . The color evaluation of Penncross creeping bentgrass maintained as a fairway turf under nontrafficked conditions during the 1989 growing season.

	Visual Color [z]					
Treatment No.	May25	June13	July5	Aug4	Sept6	Mean
1. 1x C+ 1 N	6.7	6.3	5.7	5.7	6.7	6.2
2. 1x C+ 3 N	6.7	7.3	7.3	4.3	7.0	6.5
3. 1x C+ 5 N	6.7	7.7	7.7	4.0	6.7	6.5
4. 1x C- 1 N	6.3	5.7	6.0	5.7	6.7	6.1
5. 1x C- 3 N	6.7	6.3	7.0	4.7	6.3	6.2
6. 1x C- 5 N	6.7	7.7	7.3	4.0	6.0	6.3
7. 7x C+ 1 N	7.0	6.0	6.3	5.7	7.7	6.5
8. 7x C+ 3 N	7.3	7.3	7.0	4.7	6.7	6.6
9. 7x C+ 5 N	7.0	8.0	7.3	3.3	6.3	6.4
10. 7x C- 1 N	6.3	6.0	6.0	6.3	7.7	6.5
11. 7x C- 3 N	6.7	7.0	6.7	5.3	7.0	6.5
12. 7x C- 5 N	5.7	7.7	7.3	4.3	6.3	6.3
Irr. frequency						
1x	6.6	6.8	6.8	4.7	6.6	6.3
7x	6.7	7.0	6.8	4.9	6.9	6.5
LSD(0.05)	ns	ns	ns	ns	ns	ns
Clippings						
C+	6.9a	7.1a	6.9	4.6b	6.8	6.5
C-	6.4b	6.7b	6.7	5.1a	6.7	6.3
LSD(0.05)	0.4	0.3	ns	0.4	ns	ns
N rates						
1	6.6	6.0c	6.0c	5.8a	7.2a	6.3
3	6.8	7.0b	7.0b	4.8b	6.8ab	6.5
5	6.5	7.8a	7.4a	3.9c	6.3b	6.4
LSD(0.05)	ns	0.3	0.3	0.5	0.7	ns

z Visual color was made on a 1-9 scale with 1 = brown and 9 = dark green color.

Table . The color evaluation of Penncross creeping bentgrass maintained as a fairway turf under trafficked conditions during the 1989 growing season.

	Visual Color [z]					
Treatment No.	May25	June13	July5	Aug4	Sept6	Mean
1. 1x C+ 1 N	5.7	5.7	6.3	5.7	7.0	6.1
2. 1x C+ 3 N	5.7	6.7	7.0	6.0	8.0	6.7
3. 1x C+ 5 N	5.7	7.3	7.7	5.3	7.7	6.7
4. 1x C- 1 N	6.0	5.7	6.3	5.7	7.3	6.2
5. 1x C- 3 N	6.0	6.3	7.0	6.0	8.0	6.7
6. 1x C- 5 N	5.7	8.0	7.3	6.0	7.3	6.9
7. 7x C+ 1 N	6.0	5.3	7.0	8.0	8.7	7.0
8. 7x C+ 3 N	6.0	6.3	7.0	8.7	9.0	7.4
9. 7x C+ 5 N	6.3	7.0	7.7	8.7	9.0	7.7
10. 7x C- 1 N	6.7	6.0	6.3	8.0	8.7	7.1
11. 7x C- 3 N	5.7	6.7	6.7	8.0	9.0	7.2
12. 7x C- 5 N	6.3	8.0	7.3	8.0	9.0	7.7
Irr. frequency						
1x	5.8	6.6	6.9	5.8b	7.6b	6.5b
7x	6.2	6.6	7.0	8.2a	8.9a	7.4a
LSD(0.05)	ns	ns	ns	0.3	0.4	0.2
Clippings						
C+	5.9	6.4b	7.1	7.1	8.2	6.9
C-	6.1	6.8a	6.8	6.9	8.2	7.0
LSD(0.05)	ns	0.3	ns	ns	ns	ns
N rates						
1	6.1	5.7c	6.5c	6.8	7.9b	6.6b
3	5.8	6.5b	6.9b	7.2	8.5a	7.0a
5	6.0	7.6a	7.5a	7.0	8.3b	7.3a
LSD(0.05)	ns	0.4	0.3	ns	0.6	0.3

z Visual color was made on a 1-9 scale with 1 = brown and 9 = dark green color.

Table . The fairway speed of Penncross creeping bentgrass maintained as a fairway turf <u>under nontrafficked conditions</u> during the 1989 growing season.

	Fairway Speed (cm) [z]				
Treatment No.	June21	July18	Aug17	Sept13	Mean
1. 1x C+ 1 N	234.0	206.7	209.7	186.7	209.3
2. 1x C+ 3 N	216.0	208.3	189.3	169.0	195.7
3. 1x C+ 5 N	211.0	208.0	200.3	175.7	198.8
4. 1x C- 1 N	223.3	218.0	220.0	210.3	217.9
5. 1x C- 3 N	232.3	205.7	213.7	192.3	211.0
6. 1x C- 5 N	208.3	209.3	203.3	202.3	205.8
7. 7x C+ 1 N	215.3	201.7	168.7	178.0	190.9
8. 7x C+ 3 N	217.7	190.3	172.7	187.7	192.1
9. 7x C+ 5 N	186.7	181.7	180.3	181.3	182.5
10. 7x C- 1 N	229.3	207.7	182.7	190.7	202.6
11. 7x C- 3 N	226.0	217.0	194.0	202.7	209.9
12. 7x C- 5 N	199.0	185.0	187.0	193.3	191.1
Irr. frequency					
1x	220.8	209.3a	206.1a	189.4	206.4a
7x	212.3	197.2b	180.9b	188.9	194.8b
LSD(0.05)	ns	11.8	12.4	ns	7.1
Clippings					
C+	213.4	199.4	186.8b	179.7b	194.9b
C-	219.7	207.1	200.1a	198.6a	206.4a
LSD(0.05)	ns	ns	12.4	6.9	7.1
N rates					
1	225.5a	208.5	195.3	191.4	205.2a
3	223.0a	205.3	192.4	188.0	202.2ab
5	201.3b	196	192.8	188.2	194.5b
LSD(0.05)	15.7	ns	ns	ns	8.7

z The fairway speed was determined by the mean of 8 measurements which were measured by two in every direction using a modified stimpmeter.

Table . The load bearing capacity of Penncross creeping bentgrass maintained as a fairway turf under trafficked conditions during the 1989 growing season.

	Load Bearing Capacity(Newton) [z]				
Treatment No.	June29	July31	Sept6	Oct11	Mean
1. 1x C+ 1 N	28.9	33.5	18.8	31.3	28.2
2. 1x C+ 3 N	23.3	41.5	17.0	27.5	27.3
3. 1x C+ 5 N	23.8	37.6	17.7	25.4	26.1
4. 1x C- 1 N	27.8	40.4	22.2	34.0	31.1
5. 1x C- 3 N	27.6	38.2	24.4	28.1	29.6
6. 1x C- 5 N	24.6	40.3	18.2	32.0	28.8
7. 7x C+ 1 N	25.3	40.0	20.6	26.4	28.1
8. 7x C+ 3 N	26.1	40.6	15.8	24.0	26.6
9. 7x C+ 5 N	23.8	41.7	15.9	22.8	26.1
10. 7x C- 1 N	28.6	43.0	19.7	27.6	29.7
11. 7x C- 3 N	26.1	39.7	19.2	28.5	28.4
12. 7x C- 5 N	28.8	33.7	20.1	25.0	26.9
Irr. frequency					
1x	26.0	38.6	19.7	29.7a	28.5
7x	26.4	39.8	18.6	25.7b	27.6
LSD(0.05)	ns	ns	ns	2.0	ns
Clippings					
C+	25.2	39.2	17.6b	26.2b	27.1b
C-	27.3	39.2	20.6a	29.2a	29.1a
LSD(0.05)	ns	ns	2.7	2.0	1.6
N rates					
1	27.7	39.2	20.3	29.8a	29.3a
3	25.8	40.0	19.1	27.0b	28.0ab
5	25.2	38.3	18.0	26.3b	27.0b
LSD(0.05)	ns	ns	ms	2.5	2.0

z Load bearing capacity was measured with a special divice which was designed and built in the Agricultural Engineering Department.

Table . The load bearing capacity of Penncross creeping bentgrass maintained as a fairway turf under nontrafficked conditions during the 1989 growing season.

Treatment No.	Load Bearing Capacity (Newton) z				
	June29	July31	Sept6	Oct11	Mean
1. 1x C+ 1 N	28.1	29.4	16.4	23.2	24.3
2. 1x C+ 3 N	24.0	25.4	15.1	22.4	21.7
3. 1x C+ 5 N	23.8	23.2	13.4	22.4	20.7
4. 1x C- 1 N	27.8	30.8	20.6	29.4	27.2
5. 1x C- 3 N	28.2	32.0	18.3	32.0	27.6
6. 1x C- 5 N	25.0	34.5	14.5	25.0	24.7
7. 7x C+ 1 N	30.5	24.8	15.9	20.0	22.8
8. 7x C+ 3 N	24.4	31.5	15.6	18.3	22.5
9. 7x C+ 5 N	26.1	28.3	16.7	22.2	23.3
10. 7x C- 1 N	29.4	24.8	19.8	24.9	24.7
11. 7x C- 3 N	26.4	26.4	17.0	29.1	24.7
12. 7x C- 5 N	27.3	30.1	15.9	26.8	25.0
Irr. frequency					
1x	26.2	29.2	16.4	25.7a	24.4
7x	27.3	27.7	16.8	23.5b	23.8
LSD(0.05)	ns	ns	ns	1.9	ns
Clippings					
C+	26.2	27.1	15.5b	21.4b	22.5b
C-	27.4	29.8	17.7a	27.9a	25.7a
LSD(0.05)	ns	ns	1.6	1.9	1.1
N rates					
1	29.0a	27.4	18.2a	24.4	24.7
3	25.8b	28.8	16.5ab	25.5	24.1
5	25.6b	29.0	15.1b	24.1	23.4
LSD(0.05)	2.7	ns	2.0	ns	ns

z Load bearing capacity was measured with a special divice which was designed and built in the Agricultural Engineering Department.

Table . Divoting tolerance of Penncross creeping bentgrass maintained as a fairway turf under trafficked conditions during the 1989 growing season.

	Divoting Tolerance (Aug14)					
Treatment No.	Length (cm)	Width (cm)	Depth (cm)	Area[z] (cm^2)	Volume[y] (cm^3)	Soil[x] Moisture(%)
1. 1x C+ 1 N	12.4	4.5	1.1	57.8	71.8	23.7
2. 1x C+ 3 N	7.8	1.8	0.3	28.9	14.1	37.7
3. 1x C+ 5 N	14.5	6.1	1.5	94.0	151.9	23.6
4. 1x C- 1 N	10.8	5.4	0.9	61.9	62.5	28.6
5. 1x C- 3 N	21.7	6.4	1.4	156.5	276.5	24.2
6. 1x C- 5 N	20.2	6.4	1.3	145.5	229.7	35.4
7. 7x C+ 1 N	15.7	4.8	1.6	83.0	153.9	29.3
8. 7x C+ 3 N	16.0	5.4	1.0	95.7	114.8	34.7
9. 7x C+ 5 N	22.3	6.0	1.4	142.7	234.6	32.2
10. 7x C- 1 N	22.0	6.3	1.7	142.8	229.3	38.0
11. 7x C- 3 N	21.3	5.4	1.5	131.4	235.8	37.4
12. 7x C- 5 N	14.0	5.9	1.6	92.8	171.5	33.7
Irr. frequency						
1x	15.1b	5.3	1.1	94.7	145.2	27.2b
7x	18.9a	5.5	1.5	116.2	196.0	33.8a
LSD(0.05)	2.9	ns	ns	ns	ns	3.1
Clippings						
C+	15.3b	5.0	1.2	87.9	135.3	29.0b
C-	19.1a	5.9	1.4	127.3	214.7	32.3a
LSD(0.05)	2.9	ns	ns	ns	ns	3.2
N rates						
1	14.8	5.0	1.3	81.1	123.8	28.7
3	18.3	5.1	1.2	116.7	192.2	32.6
5	17.9	6.1	1.4	118.6	195.7	30.1
LSD(0.05)	ns	ns	ns	ns	ns	ns

z Area was calculated by length x width.

y Volume was calculated by length x width x depth.

x Soil moisture content when divoting was applied, using a specially designed divot machine.

Table . Divoting tolerance of Penncross creeping bentgrass maintained as a fairway turf <u>under nontrafficked conditions</u> during the 1989 growing season.

Treatment No.	Divoting Tolerance (Aug14)					
	Length (cm)	Width (cm)	Depth (cm)	Area[z] (cm^2)	Volume[y] (cm^3)	Soil[x] Moisture(%)
1. 1x C+ 1 N	9.9	3.2	0.8	43.4	51.2	25.9
2. 1x C+ 3 N	7.6	2.3	0.5	32.0	30.0	26.1
3. 1x C+ 5 N	9.4	4.1	0.8	55.4	67.3	26.8
4. 1x C- 1 N	10.4	3.3	0.8	41.2	39.5	27.2
5. 1x C- 3 N	12.1	4.1	0.9	66.3	100.0	25.3
6. 1x C- 5 N	11.8	4.0	1.2	55.1	85.0	27.1
7. 7x C+ 1 N	14.6	4.3	1.2	79.4	138.6	32.6
8. 7x C+ 3 N	9.5	4.2	0.9	60.4	94.6	31.5
9. 7x C+ 5 N	13.4	4.9	1.3	80.6	138.5	32.4
10. 7x C- 1 N	18.6	5.4	1.4	110.8	190.1	34.8
11. 7x C- 3 N	16.2	5.3	1.7	95.8	211.8	34.2
12. 7x C- 5 N	15.1	5.3	1.3	101.0	196.4	33.4
Irr. frequency						
1x	10.2b	3.5b	0.8b	48.9b	62.2b	26.4b
7x	14.6a	4.9a	1.3a	88.0a	161.7a	33.1a
LSD(0.05)	3.2	1.1	0.3	23.3	52.1	2.2
Clippings						
C+	10.7b	3.9	0.9b	58.5	86.7	29.2
C-	14.0a	4.6	1.2a	78.4	137.2	30.3
LSD(0.05)	3.1	ns	0.3	ns	ns	ns
N rates						
1	13.4	4.1	1.0	68.7	104.9	30.1
3	11.4	4.0	1.0	63.6	109.1	29.3
5	12.4	4.6	1.1	73.0	121.8	29.9
LSD(0.05)	ns	ns	ns	ns	ns	ns

z Area was calculated by length x width.

y Volume was calculated by length x width x depth.

x Soil moisture content when divoting was applied, using a specially designed divot machine.

Table . Divot-return(D+) recovery of Penncross creeping bentgrass maintained as a fairway turf under trafficked conditions during the 1989 growing season.

Treatment No.	D+ Recovery z						
	Wk1	Wk2	Wk3	Wk4	Wk5	Wk6	Mean
1. 1x C+ 1 N	6.7	6.8	7.1	7.9	7.9	8.2	7.4
2. 1x C+ 3 N	6.3	6.9	7.2	7.7	7.9	8.3	7.4
3. 1x C+ 5 N	6.7	6.9	7.2	7.9	7.9	8.4	7.5
4. 1x C- 1 N	6.0	6.2	6.8	7.5	7.7	8.4	7.1
5. 1x C- 3 N	6.9	7.0	7.3	7.7	7.9	8.0	7.5
6. 1x C- 5 N	6.8	6.8	6.9	7.2	7.3	7.6	7.1
7. 7x C+ 1 N	7.1	7.5	7.6	8.0	8.1	8.3	7.8
8. 7x C+ 3 N	6.9	7.5	8.0	8.2	8.2	8.5	7.9
9. 7x C+ 5 N	6.3	6.9	7.3	7.6	7.8	8.2	7.4
10. 7x C- 1 N	6.3	6.7	7.2	7.3	7.8	8.1	7.2
11. 7x C- 3 N	6.8	7.1	7.5	7.8	7.9	8.2	7.5
12. 7x C- 5 N	7.1	7.2	7.8	8.2	8.4	8.7	7.9
Irr. frequency							
1x	6.6	6.8	7.1	7.6	7.8	8.2	7.3
7x	6.8	7.2	7.6	7.9	8.0	8.4	7.6
LSD(0.05)	ns	ns	ns	ns	ns	ns	ns
Clippings							
C+	6.7	7.1	7.4	7.9	8.0	8.3	7.6
C-	6.6	6.8	7.3	7.6	7.8	8.2	7.4
LSD(0.05)	ns	ns	ns	ns	ns	ns	ns
N rates							
1	6.5	6.8	7.2	7.7	7.9	8.3	7.4
3	6.7	7.1	7.5	7.8	8.0	8.3	7.6
5	6.7	7.0	7.3	7.7	7.9	8.2	7.5
LSD(0.05)	ns	ns	ns	ns	ns	ns	ns

z D+ means divot returned after divoting and D+ recovery was based on a visual scale with 1 = no recovery and 9 = complete recovery.

Table . Divot-return (D+) recovery of Penncross creeping bentgrass maintained as a fairway turf <u>under nontrafficked conditions</u> during the 1989 growing season.

	D+ Recovery [z]						
Treatment No.	Wk1	Wk2	Wk3	Wk4	Wk5	Wk6	Mean
1. 1x C+ 1 N	7.0	7.1	7.4	7.8	7.8	8.0	7.5
2. 1x C+ 3 N	8.1	8.1	8.4	8.7	8.7	9.0	8.5
3. 1x C+ 5 N	7.6	7.6	8.2	8.5	8.7	8.9	8.2
4. 1x C- 1 N	7.0	7.2	7.7	8.1	8.1	8.3	7.8
5. 1x C- 3 N	7.7	7.8	8.2	8.5	8.5	8.8	8.2
6. 1x C- 5 N	7.5	7.8	8.1	8.6	8.6	8.7	8.2
7. 7x C+ 1 N	7.5	7.5	8.0	8.3	8.4	8.7	8.1
8. 7x C+ 3 N	7.9	8.0	8.6	8.8	8.9	9.0	8.5
9. 7x C+ 5 N	7.7	8.1	8.5	8.7	8.7	8.9	8.4
10. 7x C- 1 N	7.5	7.9	8.2	8.5	8.5	8.8	8.2
11. 7x C- 3 N	6.7	6.9	7.8	8.0	8.2	8.6	7.7
12. 7x C- 5 N	7.6	7.9	8.3	8.6	8.7	8.9	8.3
Irr. frequency							
1x	7.5	7.6	8.0	8.4	8.4	8.6	8.1
7x	7.5	7.7	8.2	8.5	8.6	8.8	8.2
LSD(0.05)	ns	ns	ns	ns	ns	ns	ns
Clippings							
C+	7.6	7.7	8.2	8.5	8.5	8.7	8.2
C-	7.3	7.6	8.1	8.4	8.4	8.7	8.1
LSD(0.05)	ns	ns	ns	ns	ns	ns	ns
N rates							
1	7.3	7.4	7.9	8.2	8.2	8.5	7.9
3	7.6	7.7	8.3	8.5	8.6	8.8	8.2
5	7.6	7.8	8.3	8.6	8.6	8.8	8.3
LSD(0.05)	ns	ns	ns	ns	ns	ns	ns

z D+ means divot returned after divoting and D+ recovery was based on a visual scale with 1 = no recovery and 9 = complete recovery.

Table . Divot-removal(D-) recovery of Penncross creeping bentgrass maintained as a fairway turf under trafficked conditions during the 1989 growing season.

	D- Recovery [z]						
Treatment No.	Wk1	Wk2	Wk3	Wk4	Wk5	Wk6	Mean
1. 1x C+ 1 N	6.3	6.7	6.9	7.4	7.4	7.8	7.1
2. 1x C+ 3 N	5.8	6.0	6.4	7.0	7.2	7.8	6.7
3. 1x C+ 5 N	4.1	4.5	4.9	5.4	5.6	6.3	5.1
4. 1x C- 1 N	4.9	5.1	5.4	6.1	6.2	6.7	5.7
5. 1x C- 3 N	5.5	5.5	5.8	6.2	6.2	6.7	6.0
6. 1x C- 5 N	4.7	4.8	5.1	5.6	5.8	6.2	5.4
7. 7x C+ 1 N	5.8	6.1	6.6	7.0	7.2	7.7	6.7
8. 7x C+ 3 N	5.0	5.7	6.0	6.5	6.6	7.2	6.1
9. 7x C+ 5 N	5.4	5.9	6.6	7.0	7.1	7.6	6.6
10. 7x C- 1 N	4.8	5.1	5.7	6.3	6.6	7.0	5.9
11. 7x C- 3 N	4.3	4.9	5.5	6.1	6.4	7.0	5.7
12. 7x C- 5 N	4.9	5.2	5.8	6.2	6.3	6.8	5.9
Irr. frequency							
1x	5.2	5.4	5.8	6.3	6.4	6.9	6.0
7x	5.0	5.5	6.0	6.5	6.7	7.2	6.2
LSD(0.05)	ns	ns	ns	ns	ns	ns	ns
Clippings							
C+	5.4	5.8	6.2	6.7	6.8	7.4	6.4
C-	4.9	5.1	5.5	6.1	6.3	6.7	5.8
LSD(0.05)	ns	ns	ns	ns	ns	ns	ns
N rates							
1	5.4	5.7	6.1	6.7	6.8	7.3	6.4
3	5.2	5.5	5.9	6.5	6.6	7.2	6.1
5	4.8	5.1	5.6	6.1	6.2	6.7	5.7
LSD(0.05)	ns	ns	ns	ns	ns	ns	ns

z D- means divot removed after divoting and D- recovery was based on a visual scale with 1 = no recovery and 9 = complete recovery.

Table . Divot-removal(D-) recovery of Penncross creeping bentgrass maintained as a fairway turf under nontrafficked conditions during the 1989 growing season.

	D- Recovery [z]						
Treatment No.	Wk1	Wk2	Wk3	Wk4	Wk5	Wk6	Mean
1. 1x C+ 1 N	6.5	6.6	7.0	7.6	7.7	7.9	7.2
2. 1x C+ 3 N	6.2	6.3	6.9	7.4	7.4	7.9	7.0
3. 1x C+ 5 N	6.1	6.2	6.7	7.0	7.0	7.6	6.8
4. 1x C- 1 N	5.7	6.0	6.4	6.8	6.8	7.2	6.5
5. 1x C- 3 N	4.6	4.9	5.5	6.0	6.1	6.5	5.6
6. 1x C- 5 N	5.8	5.9	6.1	6.8	6.9	7.3	6.5
7. 7x C+ 1 N	5.8	5.9	6.2	6.9	6.9	7.3	6.5
8. 7x C+ 3 N	6.2	6.6	7.1	7.3	7.4	7.8	7.1
9. 7x C+ 5 N	5.9	6.2	6.9	7.2	7.3	7.7	6.9
10. 7x C- 1 N	4.4	4.5	4.9	5.4	5.7	6.2	5.2
11. 7x C- 3 N	5.1	5.5	5.9	6.2	6.3	6.8	6.0
12. 7x C- 5 N	5.0	5.1	5.7	6.1	6.6	7.1	5.9
Irr. Frequency							
1x	5.8	6.0	6.4	6.9	7.0	7.4	6.6
7x	5.4	5.6	6.1	6.5	6.7	7.2	6.3
LSD(0.05)	ns	ns	ns	ns	ns	ns	ns
Clippings							
C+	6.1a	6.3a	6.8a	7.2a	7.3a	7.7a	6.9a
C-	5.1b	5.3b	5.8b	6.2b	6.4b	6.9b	5.9b
LSD(0.05)	0.7	0.7	0.7	0.7	0.6	0.6	0.7
N rates							
1	5.6	5.7	6.1	6.7	6.8	7.2	6.3
3	5.5	5.8	6.4	6.7	6.8	7.3	6.4
5	5.7	5.9	6.3	6.8	6.9	7.4	6.5
LSD(0.05)	ns	ns	ns	ns	ns	ns	ns

z D- means divot removed after divoting and D- recovery was based on a visual scale with 1 = no recovery and 9 = complete recovery.

Table . Thatch accumulation of Penncross creeping bentgrass maintained as a fairway turf under trafficked conditions during the 1989 growing season.

	Thatch Depth (mm) [z]				
Treatment No.	June1	July10	Aug10	Sept29	Mean
1. 1x C+ 1 N	9.6	10.3	10.0	11.8	10.4
2. 1x C+ 3 N	10.0	10.0	10.4	11.3	10.5
3. 1x C+ 5 N	10.6	10.2	9.0	11.9	10.4
4. 1x C- 1 N	10.2	10.0	9.0	11.6	10.2
5. 1x C- 3 N	9.5	9.5	9.6	12.2	10.2
6. 1x C- 5 N	10.5	9.6	9.3	11.5	10.2
7. 7x C+ 1 N	9.9	9.9	11.1	12.1	10.8
8. 7x C+ 3 N	9.8	9.9	11.2	12.2	10.8
9. 7x C+ 5 N	9.8	10.6	11.4	12.6	11.1
10. 7x C- 1 N	10.8	10.1	11.1	11.8	11.0
11. 7x C- 3 N	9.5	9.6	10.1	12.2	10.4
12. 7x C- 5 N	9.5	10.1	10.2	12.3	10.5
Irr. frequency					
1x	10.1	10.0	9.6b	11.7	10.3b
7x	9.9	10.1	10.9a	12.2	10.8a
LSD(0.05)	ns	ns	0.4	ns	0.3
Clippings					
C+	10.0	10.2	10.5a	12.0	10.7
C-	10.0	9.8	9.9b	11.9	10.4
LSD(0.05)	ns	ns	0.4	ns	ns
N rate					
1	10.1	10.1	10.3	11.8	10.6
3	9.7	9.8	10.3	12.0	10.4
5	10.1	10.1	10.0	12.1	10.6
LSD(0.05)	ns	ns	ns	ns	ns

z Thatch depth was determined by the mean of 6 thatch measurements per plot.

Table . Thatch accumulation of Penncross creeping bentgrass maintained as a fairway turf <u>under nontrafficked conditions</u> during the 1989 growing season.

	Thatch Depth(mm) [z]				
Treatment No.	June1	July10	Aug10	Sept29	Mean
1. 1x C+ 1 N	11.3	10.9	11.5	12.9	11.7
2. 1x C+ 3 N	11.2	9.3	11.7	12.7	11.2
3. 1x C+ 5 N	9.8	11.0	10.6	12.5	11.0
4. 1x C- 1 N	11.2	10.5	10.0	11.8	10.9
5. 1x C- 3 N	10.7	11.3	10.6	12.9	11.4
6. 1x C- 5 N	11.8	10.5	10.5	12.0	11.2
7. 7x C+ 1 N	11.6	10.3	12.0	12.7	11.7
8. 7x C+ 3 N	9.8	10.5	12.3	13.7	11.6
9. 7x C+ 5 N	11.1	11.8	12.8	12.3	12.0
10. 7x C- 1 N	11.5	11.5	11.7	12.2	11.7
11. 7x C- 3 N	10.3	11.5	11.8	12.3	11.5
12. 7x C- 5 N	10.7	11.5	11.5	12.2	11.5
Irr. frequency					
1x	10.9	10.7	10.8b	12.5	11.2
7x	10.9	11.2	12.1a	12.5	11.7
LSD(0.05)	ns	ns	0.6	ns	ns
Clippings					
C+	10.9	10.8	11.8a	12.7	11.6
C-	10.9	11.2	11.1b	12.3	11.4
LSD(0.05)	ns	ns	0.6	ns	ns
N rates					
1	10.4	10.7	11.5	12.5	11.3
3	10.5	10.9	11.5	12.8	11.4
5	10.7	11.2	11.5	12.3	11.4
LSD(0.05)	ns	ns	ns	ns	ns

z Thatch depth was determined by the mean of 6 thatch measurements per plot.

Table . Soil bulk density of Penncross creeping bentgrass maintained as a fairway turf under trafficked conditions during the 1989 growing season.

	Soil Bulk Density (g/cc) [z]		
Treatment No.	July 25	Sept 20	Mean
1. 1x C+ 1 N	1.187	1.127	1.157
2. 1x C+ 3 N	1.200	1.143	1.172
3. 1x C+ 5 N	1.227	1.110	1.168
4. 1x C- 1 N	1.150	1.153	1.152
5. 1x C- 3 N	1.160	1.170	1.165
6. 1x C- 5 N	1.187	1.107	1.147
7. 7x C+ 1 N	1.197	1.117	1.157
8. 7x C+ 3 N	1.237	1.160	1.198
9. 7x C+ 5 N	1.237	1.123	1.180
10. 7x C- 1 N	1.187	1.197	1.192
11. 7x C- 3 N	1.237	1.170	1.203
12. 7x C- 5 N	1.200	1.163	1.182
Irr. frequency			
1x	1.185b	1.135	1.160b
7x	1.216a	1.155	1.185a
LSD(0.05)	0.012	ns	0.016
Clippings			
C+	1.214a	1.130b	1.172
C-	1.187b	1.160a	1.173
LSD(0.05)	0.012	0.029	ns
N rates			
1	1.180b	1.148	1.164b
3	1.208a	1.161	1.185a
5	1.213a	1.126	1.169ab
LSD(0.05)	0.015	ns	0.019

z Soil bulk density was determined by the mean of bulk density of 4 soil cores per plot.

Table . Soil bulk density of Penncross creeping bentgrass maintained as a fairway turf under nontrafficked conditions during the 1989 growing season.

Treatment No.	Soil Bulk Density (g/cc) [z] July 25	Sept 20	Mean
1. 1x C+ 1 N	1.160	1.157	1.158
2. 1x C+ 3 N	1.170	1.117	1.143
3. 1x C+ 5 N	1.217	1.177	1.197
4. 1x C- 1 N	1.197	1.173	1.185
5. 1x C- 3 N	1.120	1.153	1.137
6. 1x C- 5 N	1.187	1.150	1.168
7. 7x C+ 1 N	1.190	1.180	1.185
8. 7x C+ 3 N	1.240	1.087	1.163
9. 7x C+ 5 N	1.220	1.157	1.188
10. 7x C- 1 N	1.210	1.153	1.182
11. 7x C- 3 N	1.237	1.207	1.222
12. 7x C- 5 N	1.247	1.140	1.193
Irr. frequency			
1x	1.175b	1.154	1.165
7x	1.224a	1.153	1.189
LSD(0.05)	0.018	ns	ns
Clippings			
C+	1.199	1.146	1.172
C-	1.199	1.163	1.181
LSD(0.05)	ns	ns	ns
N rates			
1	1.189b	1.166	1.178
3	1.192b	1.141	1.166
5	1.218a	1.156	1.187
LSD(0.05)	0.022	ns	ns

z Soil bulk density was determined by the mean of bulk density of 4 soil cores per plot.