Traffic and Cultural Practice Interactions on the Leaf and Soil Nitrogen Contents of 'Penncross' Creeping Bentgrass (*Agrostis palustris* Huds.) Fairway Turf

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답압조건의 크리핑 벤트그라스 훼어웨이에서 여러가지 잔디관리방법이 엽조직 및 토양 질소함유량에 미치는 상호작용효과

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ABSTRACT

Research was initiated to evaluate both individual and interactive effects of cultural practices on the leaf and soil nitrogen content. The investigation was conducted on a 'Penncross' creeping bentgrass turf under the simulated traffic conditions from 1989 to 1991. Traffic simulation was applied as 5 passes of the wear simulator over the turf twice weekly during the growing season. A split-split-plot experimental design was used. Daily or biweekly irrigation, clipping return or removal, and 5, 15, or 25 g N m^{-2} yr^{-1} were the main-, sub-, and sub-sub-plot treatments, respectively. Treatments were replicated 3 times in a randomized complete block design. Soil and leaf tissue nitrogen content were evaluated twice in 1989 and three times in 1990 and 1991.

Both individual and interactive effects on the leaf nitrogen content were observed under the trafficked conditions. In the irrigation frequency x nitrogen treatment interaction response of 1989, leaf nitrogen content quadratically increased from 3.51 to 3.94% with nitrogen rates in combination with daily irrigation treatment. In plots treated with high-N (25 g N m^{-2} yr^{-1}), approximate 4% more leaf nitrogen content was associated with daily irrigation rather than biweekly irrigation. The nitrogen rate treatment was effective in leaf tissue nitrogen content in both 1990 and 1991. In 1990 leaf nitrogen content quadratically increased from 3.50 to 4.25% with nitrogen rate. High-N treatment (25 g N m^{-2} yr^{-1}) was a significant contributing factor to leaf tissue nitrogen content. The high-N treatment plots

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had 21% and 10% more leaf nitrogen content in 1990 and 1991, respectively, when compared to low-N treatment plots (5 g N m^{-2} yr^{-1}).

Leaf nitrogen content varied with time after establishment. At the low-N level treatment (5 g N m^{-2} yr^{-1}), plots sampled in 1991 had 20% more leaf nitrogen content, as compared to plots sampled in 1990. With the high-N rate (25 g N m^{-2} yr^{-1}), plots analyzed in 1991 were 8% higher than that of plots analyzed in 1990. Accordingly, superintendent could gradually reduce annual amount of nitrogen application in the turfgrass management with time after establishment, based on soil and leaf tissue analysis. Different responses between trafficked and nontrafficked turfs demonstrate result from the turfgrass research under the nontrafficked conditions should be carefully used, when recommended to the sports turf, depending on the intensity of traffic. Strategic management approaches are strongly recommended for the sports turf from a standpoint of the traffic intensity.

Key words: Simulated traffic conditions, Cultural practices, *Agrostis palustris* Huds., 'Penncross' creeping bentgrass fairway, Leaf N content, Wear simulator

INTRODUCTION

Mowing, fertilizing, and watering are the most fundamental and important cultural practices. These influence turfgrass quality and playing conditions and are highly interactive. Several researchers reported cultural practices were interrelated and a combination of management approaches was needed to maintain quality turf (Christians *et al.*, 1981; Erusha, 1990; Gaussoin and Branham, 1989; Kim, 1992 and 1998). Accordingly, interactive responses among these practices should be considered in a turfgrass management program to maintain acceptable quality and playability. Turfgrass management researches have been mostly focused on a single factor, such as a response to irrigation, mowing, or fertility and so on (Cuddeback and Petrovic, 1985; Dipaola and Lewis, 1989; Juska and Hanson, 1969; Schmidt and Breuninger, 1981; Shearman, 1986). Factors limiting interaction studies have been the large number of experimental units required and the resources necessary to execute the experiments. Development of innovative statistical designs and analysis has increased the feasibility of multiple component researches. Consequently, research investigating individual and interactive effects of cultural practices on several characteristics such as turf quality, playability, thatch accumulation, soil and leaf tissue nutrients etc. is possible to obtain greater accuracy for interpretation.

Kentucky bluegrass (*Poa pratensis* L.) has been used as the primary fairway species across a wide range of conditions and cultural practices in northern regions (Beard, 1982; Christians, 1990). Recent trends in cultural practice systems have emphasized closer mowing heights, as well as frequent irrigation and moderate to high nitrogen nutrition to meet expectations for fairway turf quality and playability. Kentucky bluegrass, however, is intolerant of the mowing height perceived as needed by the golfer. Thus, a trend has been toward a fairway conversion to creeping bentgrass, because it tolerates lower mowing heights than Kentucky bluegrass and also provides an excellent playing surface (Christians, 1990).

Soil test is the best way of monitoring the nutritional composition of turfgrass and can be an important tool in developing sound management practices (Carrow, 1995; Christians, 1993). Also, leaf tissue testing can provide a beneficial guide for developing fertilization programs, when correlated with a timely and properly interpretated soil analysis (Dara, 1996; Jones *et al.*, 1991). Information is readily available on the effects of cultural practices on Kentucky bluegrass turf (Christians *et al.*, 1981; Erusha, 1990; O'Neil and Carrow, 1982; Schmidt and Breuninger, 1981). However, responses of 'Penncross' creeping bentgrass turf to various fairway cultural practices are not well-established or supported by research results, since it has been used most commonly on putting greens in the cool and transitional climatic regions (Anonymous, 1988; Beard, 1982; Ferguson, 1969; Kim, 1997). Particularly, even more limited is information on soil and leaf tissue composition from turfgrass management researches done under trafficked conditions. Research was initiated to evaluate individual and interactive effects of primary cultural practices on the leaf tissue and soil nitrogen content of 'Penncross' creeping bentgrass fairway turf maintained under the simulated traffic conditions.

MATERIALS AND METHODS

This investigation was conducted at the John Seaton Anderson Turfgrass Research Facility located near Mead, Nebraska, USA. A creeping bentgrass fairway turf was established from seeding 'Penncross' creeping bentgrass in May, 1988. The soils were classified as a Sharpsburg silty-clay loam (Typic Argiudoll). The study was accomplished under the simulated traffic conditions. Traffic application was initiated in May and terminated in September from 1989 to 1991. Traffic simulation was applied as 5 passes of the wear simulator over the turf twice weekly during a growing season. A specially-designed wear simulator constructed of two steel rollers (0.36 m diam. by 1.1 m long and weighing 318 kg) was used for traffic simulation (Fig. 1). Metal golf spikes were inserted into the rollers on 76 mm centers. The two rollers were driven by a bicycle chain wrapped around two sprockets of different diameter and tooth number. The different

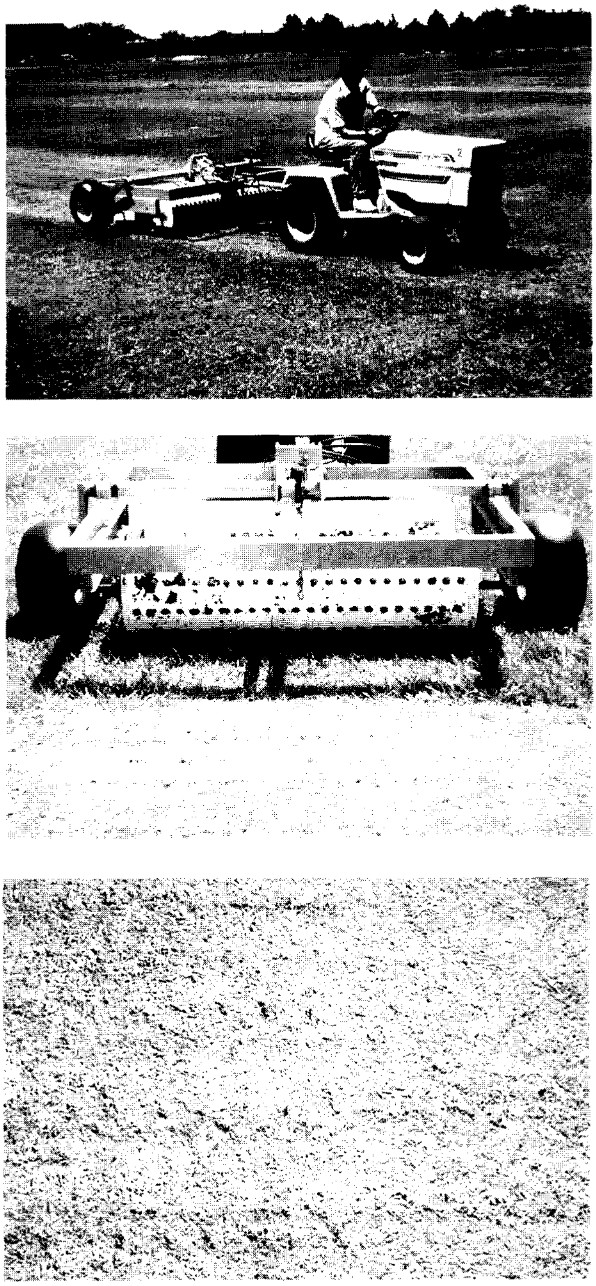

Fig. 1. A specially-designed wear simulator constructed of two steel rollers (0.36 m diam. by 1.1 m long and weighing 318 kg) was used for traffic simulation. Metal golf spikes were inserted into the rollers on 76 mm centers. The two rollers were driven by a bicycle chain wrapped around two sprockets of different diameter and tooth number. A hydraulic cylinder was used to raise and lower the drum to apply wear treatments and the wear simulator was pulled by a lawn tractor. Front (top) and rear view (middle) of the wear simulator used to apply wear treatments and 'Penncross' creeping bentgrass fairway turf (bottom) after being simulated with wear simulator.

sized sprockets caused both horizontal and vertical wear forces on the turfgrass. A hydraulic cylinder was used to raise and lower the drum to apply wear treatments. The wear simulator was pulled by a lawn tractor (John Deere 316, Deere & Co., Moline, IL).

A split-split-plot experimental design was used for the treatment arrangement. Irrigation frequency treatments were assigned to the main-plot (9 m by 13.5 m). Irrigation rate was based on 80% potential evapotranspiration (ETp) applied daily or twice on a weekly basis. The 80% ETp rate was determined by the Nebraska modified Penman equation (Rosenberg *et al.*, 1983). Rainfall was subtracted from the required replacement amount prior to irrigation. Weather data for the calculation of ETp were collected from an automated weather station located at the site of research. Clipping return or removal constituted the sub-plot treatments (4.5 m × 13.5 m). The turf was mowed 4 times weekly at a 12 mm (0.5") height of cut (bench setting), using a Jacobsen Park 30 mower (Jacobsen Manufacturing Co., Racine, WI). Three nitrogen levels of 5 (low-N), 15 (medium-N), and 25 (high-N) g N m^{-2} yr^{-1} comprised the sub-sub-plot treatments (4.5 m by 4.5 m). Urea (46N-0-0) was used as the nitrogen carrier. Nitrogen treatments were applied in 6 equal applications from May to October. A total of 12 treatment combinations were replicated 3 times in a randomized complete block design.

Cultural practices followed a typical maintenance program for a highly-managed golf course fairway. Mowing direction was changed each time to encourage an upright growth pattern and to minimize differential soil compaction. Vertical mowing was done in October to control thatch. Core cultivation was done in May and October to reduce soil compaction and to improve turfgrass growth. Potassium sulfate (0-0-41.5K) was applied in 3 equal applications (May, June, and September) for a total of 15 g K m^{-2} yr^{-1}. A single application of superphosphate (0-19.8P-0) was applied in late September at 5 g P m^{-2} yr^{-1}. Pesticides were applied on a curative basis.

Analyses of the leaf tissue and soil nitrogen content were made twice (July and September) in 1989 and three times (May, July, and September) in both 1990 and 1991. Leaf samples were collected from turfgrass plants in the treatment plots, dried immediately at 70℃ for 48 hours, and analyzed for total-N content, using the Kjeldahl method (Bremner and Mulvaney, 1982). Concurrently, six soil cores (18 mm diam. by 200 mm depth) were collected, air dried, and analyzed for total-N content. Nitrogen analyses on the soil and leaf samples were made in the Soil and Plant Analytical Laboratory at the University of Nebraska, Lincoln, USA.

Data were analyzed as a split-split-plot with analysis of variance (ANOVA), using the General Linear Model procedures and the Statistical Analysis System (SAS Institute, 1990). The level of significance selected for treatment effects was $P \leq 0.05$. ANOVA results for all treatment effects are listed in Tables 1 and 3. The split-split-plot design used in the study allowed assessment of individual and interactive responses (Steel and Torrie, 1980). Interpretations were focused on the interactive effects rather than the main effects, when significant interactions were found among treatments. Irrigation frequency and clipping treatment means were separated by Fisher's protected least significant differences at $P \leq 0.05$, when interactive effects were not significantly observed. Planned comparisons on nitrogen treatment means were performed by orthogonal polynomial contrasts to test for significant linear or quadratic responses and an appropriate regression model was generated.

RESULTS AND DISCUSSION

Individual and interactive effects on the leaf tissue nitrogen content were observed in a 'Penncross' creeping bentgrass fairway turf grown under the simulated trafficked conditions (Table 1). In 1989, the leaf nitrogen content was affected by irrigation frequency x nitrogen treatment interaction. As nitrogen rates increased from 5 to 25 g N m^{-2} yr^{-1}, leaf nitrogen content quadratically increased from 3.51 to 3.94% in combination with daily irrigation treatment (Table 2). Under biweekly irrigation treatment the leaf nitrogen content was 3.53%, 3.83% and 3.79% in plots treated with low-N (5), medium-N (15), and high-N (25 g N m^{-2} yr^{-1}) applications, respectively. In plots treated with high-N application, more leaf nitrogen content was associated with daily irrigation rather than biweekly irrigation. Approximate 4% more leaf nitrogen content is linked with daily

Table 1. Significance levels (PR>F) of split-split-plot for leaf tissue nitrogen content on 'Penncross' creeping bentgrass fairway turf under trafficked conditions during the study. Treatments were arranged in a split-split-plot experimental design with irrigation frequency as the main-plot, clipping return or removal as the sub-plot, and nitrogen rate as the sub-sub-plot

Source	1989	1990	1991
Irrigation frequency (I)	0.95	0.46	0.80
Clippings (C)	0.17	0.16	0.91
I × C	0.99	0.54	0.31
Nitrogen rate (N)			
N linear	0.00	0.00	0.00
N quadratic	0.25	0.00	0.26
I × N linear	0.19	0.64	0.09
I × N quadratic	0.05	0.30	0.93
C × N linear	0.10	0.25	0.75
C × N quadratic	0.86	0.20	0.20
I × C × N linear	0.70	0.60	0.72
I × C × N quadratic	0.34	0.63	0.44

Table 2. Irrigation frequency × nitrogen interaction means for leaf nitrogen content (1989) of 'Penncross' creeping bentgrass fairway turf under trafficked conditions

Nitrogen rate	Irrigation frequency[a]	
	Biweekly	Daily
	%	
5 g N m^{-2} yr^{-1}	3.53[b]	3.51
15	3.83	3.68
25	3.79	3.94

[a]Irrigation was based on 80% ETp applied daily or once every three to four days on a weekly basis.

[b]LSD (P=0.05) = 0.48 for irrigation frequency treatments at the same nitrogen level. LSD = (P=0.05) = 0.12 for nitrogen rate treatments at the same irrigation frequency level.

irrigation and high-N treatment combinations. With traffic application over the plots initiated from 1989, however, irrigation frequency treatment became ineffective in increasing leaf nitrogen content in the study. As shown in Table 2, irrigation frequency treatment did not significantly influence leaf nitrogen content at any nitrogen rate. This response was attributed to the decreased water infiltration and percolation in the plots under trafficked conditions. O'Neil and Carrow (1982) noted reduced water use for compacted conditions in Kentucky bluegrass turf.

The nitrogen rate treatment was effective in leaf tissue nitrogen content in both 1990 and 1991 (Table 1). In 1990 leaf nitrogen content quadratically increased from 3.50 to 4.25% as nitrogen application rate changed from 5 to 25 g N m^{-2} yr^{-1} (Fig. 2). High-N treatment (25 g N m^{-2} yr^{-1}) was a significant contributing factor to leaf tissue nitrogen content. Plots applied with high-N treatment (25 g N m^{-2} yr^{-1}) had 21% more leaf nitrogen content, compared to plots with low-N treatment (5 g N m^{-2} yr^{-1}). Similar responses were also found in 1991. Leaf nitrogen content increased with nitrogen application rate. The leaf nitrogen content was 4.20%, 4.50%, and 4.60% in low-N (5), medium-N (15), and high-N (25 g N m^{-2} yr^{-1}) treatments, respectively. Approximate 10% more leaf nitrogen content was associated with high-N treatment (25 g N m^{-2} yr^{-1}), as compared with low-N treatment (5 g N m^{-2} yr^{-1}). These findings were supported by data from other studies. Goss and Law (1967) reported high-N rate (38 g N m^{-2} yr^{-1}) resulted in increased leaf tissue nitrogen content in the bluegrass, compared to low-N rate (12 g N m^{-2} yr^{-1}). In a study with creeping bentgrass under nontraffic conditions by Kim and Shearman (1997), plots applied with high-N level (25 g N m^{-2} yr^{-1}) had 10 to 17% more nitrogen content in leaf tissue, when compared with plots applied with low-N level (5 g N m^{-2} yr^{-1}).

Leaf nitrogen content was also variable with time. Observational comparisons during

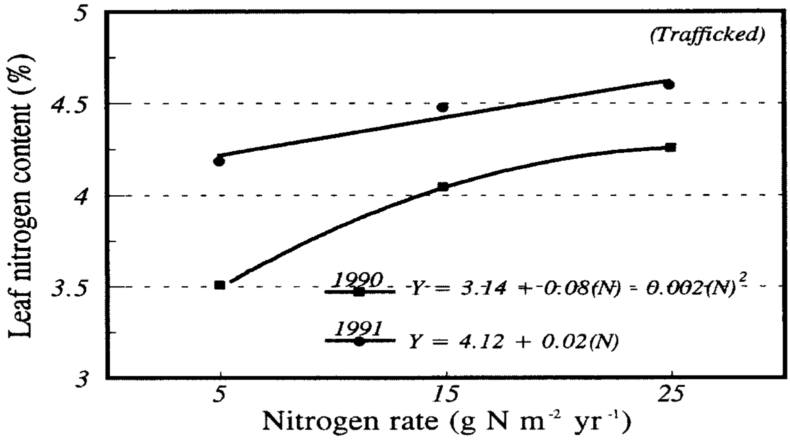

Fig. 2. Effects of nitrogen nutrition rate on leaf nitrogen content (1990 - 91) of 'Penncross' creeping bentgrass fairway turf under trafficked conditions.

the study indicated that leaf tissue nitrogen content increased at any nitrogen rate with time after establishment. At the low-N level treatment (5 g N m^{-2} yr^{-1}), turfgrass plants in the plots sampled in 1991 had 20% more leaf nitrogen content, as compared to those in the plots sampled in 1990 (Fig. 2). Similar response was also found in the plots treated with high-N rate (25 g N m^{-2} yr^{-1}). Turfgrass plants analyzed in 1991 were 8% higher in the leaf tissue nitrogen content than those in 1990. Nitrogen content in the leaf tissue would accumulate over years. Kim and Shearman (1997) reported leaf tissue nitrogen content increased at any nitrogen rate ranged between 5 and 25 g N m^{-2} yr^{-1} after planting creeping bentgrass under the nontraffic conditions. These findings demonstrate the turfgrass nutrients might increase with time after planting, depending upon edaphic environments and cultural practices employed. Therefore, our data suggest that superintendent could gradually reduce annual amount of nitrogen application in the management of golf course turf with time after establishment, based on soil and leaf tissue analysis. Regular analysis of leaf tissues in the golf courses must be done and a reasonable recommendation for the fertilization program should be developed through the incorporation of its analytic result. Dara (1996) reported frequent tissue testing correlated with a soil analysis is an effective valuable tool for planning and monitoring a turfgrass fertility program.

It was considered in the study that irrigation frequency and clipping treatments unlike responses of nitrogen rate treatment were not a significant factor, influencing leaf tissue nitrogen content (Table 1). Daily or biweekly irrigation did not affect the nitrogen content for the first three years, except the interaction response between the irrigation frequency and nitrogen treatment in 1989. Also, clipping treatments was not a factor affecting leaf tissue nitrogen content over the first three years after establishment. However, in the experiment under nontraffic conditions, clippings were a very significant factor, influencing leaf tissue nitrogen content. Areas returned with clippings had 5 to 8% more nitrogen content in the leaf tissue, when compared to clipping-removed areas (Kim, 1992; Kim and Shearman, 1997). A possible explanation for different clipping responses between trafficked and nontrafficked turfs is poor soil aeration of the trafficked area. Turgeon (1996) speculated microbial activity for decomposing organic matter was inhibited in oxygen-deficient soils under a compacted conditions. Intensive and increasing traffic is being applied to the golf course turf, caused by foot, vehicle, equipment and so on (Beard, 1982; Carrow and Petrovic, 1992). Accordingly, different responses between trafficked and nontrafficked turfs demonstrate data of the turfgrass research under nontrafficked conditions should be carefully used, when recommended to the sports turf, depending on the intensity of traffic.

No significant treatment effects were observed for soil nitrogen content over the first three years since 'Penncross' creeping bentgrass establishment (Table 3). Similar response was observed in the nontraffic study (Kim, 1992; Kim and Shearman, 1997). Several factors might be associated with this response, such as the heterogeneous characteristics of soil medium, the soil sampling depth, and early stage for analysis in turf stand of being only three years after establishment. In the preparation of soil samples, however, sampling and analyzing by soil depths is recommended to predict difference of soil nutrients.

Table 3. Significance levels (PR>F) of split-split-plot for soil nitrogen content on 'Penncross' creeping bentgrass fairway turf under trafficked conditions during the study. Treatments were arranged in a split-split-plot experimental design with irrigation frequency as the main-plot, clipping return or removal as the sub-plot, and nitrogen rate as the sub-sub-plot

Source	1989	1990	1991
Irrigation frequency (I)	0.86	0.61	0.50
Clippings (C)	0.81	0.31	0.76
I × C	0.47	0.71	0.78
Nitrogen rate (N)			
N linear	0.91	0.70	0.54
N quadratic	0.82	0.73	0.72
I × N linear	0.41	0.30	0.41
I × N quadratic	0.40	0.09	0.19
C × N linear	0.83	0.58	0.37
C × N quadratic	0.36	0.41	0.76
I × C × N linear	0.50	0.53	0.30
I × C × N quadratic	0.96	0.82	0.32

In conclusion, traffic and several management factors influenced the leaf tissue nitrogen content in a 'Penncross' creeping bentgrass fairway turf. Our study indicates leaf tissue nitrogen content changes with irrigation frequency associated with high-N treatment (25 g N m^{-2} yr^{-1}), nitrogen application rate and time after establishment. Much more leaf nitrogen content with daily irrigation rather than biweekly irrigation in the high-N (25 g N m^{-2} yr^{-1}) plots supports that frequent irrigation be needed for nitrogen uptake by the leaf tissues, paticularly under the trafficked areas. This response agreed with the turfgrass color and quality evaluation in a research conducted with 'Penncross' creeping bentgrass turf (Kim, 1992; Kim *et al.*, 1991).

Data from this investigation indicate the feasibility of different responses between trafficked and nontraffricked turfs such as clipping treatment response only under the nontraffic conditions (Kim and Shearman, 1997) and interactive response only under the traffic conditions of this study, even though the same cultural practices are employed. Therefore, it is necessary to execute strategic management approaches for the sports turf according to the traffic intensity. It has been reported that nutrient uptake and nutrient rations in many plant species were altered by compacted conditions (Cannell, 1977; Castillo et. al., 1982; Grable, 1966; Parish, 1971; Veen, 1988). In turf areas where heavy traffic is expected, turf manager should consider that frequent irrigation is much better for high-N rate applied area for the uptake of nitrogen and clippings do not significantly contribute turfgrass nutrition. Interactive responses from the simulated traffic conditions also demonstrate a strong need for a combination of management practices in areas where heavy traffic occurs by foot, vehicle, equipment and so on.

요 약

Wear simulator로 답압이 가해진 크리핑 벤트그라스 (*Agrostis palustris* Huds.) 훼어웨이에서 관수방법 · 예지물 순환 및 질소시비수준의 여러 가지 잔디관리 요인이 엽조직 및 토양질소 함유량에 미치는 효과를 알아보기 위해 본 연구를 수행하였다. 연구포장은 'Penncross' 크리핑 벤트그라스 잔디밭으로 1988년에 sharpsburg silty-clay loam (Typic Argiudoll) 토양에 조성하였으며, 실험은 1989년부터 1991년까지 3년간 수행하였다. Split-split-plot 실험디자인을 사용하여 주구에 daily or biweekly irrigation, 세구에 clipping return or removal, 세세구에 low-N (5g), moderate-N (15g), high-N (25g N m^{-2} yr^{-1}) 처리를 난괴법 3 반복으로 배치하였다. 생육기간중 잔디예초는 12 mm 예고로 일주일에 4번 실시하였고, 기타 잔디관리는 high maintenance 수준으로 유지되는 한지형 양잔디 훼어웨이 기준으로 실시하였다. 엽조직 및 토양샘플은 1989년 2회, 1990년과 1991년에는 3회씩 채취하여, 네브라스카 주립대 토양식물분석실에서 분석하였다.

답압이 가해진 크리핑 벤트그라스 훼어웨이 잔디에서 엽조직 질소함유량은 여러 가지 잔디관리 방법간 상호작용 효과가 관찰되었다. 1989년 나타난 질소시비수준과 관수방법간의 상호작용에서 daily irrigation 지역의 엽질소 함유량은 질소시비량이 low-N 수준에서 high-N 수준으로 증가함에 따라 3.51%에서 3.94%로 quadratic pattern으로 증가하였다. High-N 처리지역에서 엽질소 함유량은 daily irrigation 관수방법이 biweekly irrigation 관수방법보다 약 4% 정도 더 많은 것으로 나타났다. 엽질소 함유량은 특히 질소시비 수준에 따라 크게 영향을 받는 것으로 나타났다. 1990년 질소시비량이 low-N 수준에서 high-N 수준으로 증가함에 따라 3.50%에서 4.25%로 quadratic pattern으로 증가하였고, 1991년에는 4.20%에서 4.60%까지 linear pattern 으로 증가하였다. High-N 처리구의 엽조직 질소함유량은 low-N 처리구와 비교시 1990년에는 21%, 1991년에는 10% 더 많은 것으로 나타났다. 잔디조성후 시간이 경과함에 따라 엽조직의 질소함유량도 증가하였다. Low-N 수준에서 1991년 엽질소 함유량은 1990년에 비해 20% 증가하였으며, high- N 수준에서는 1991년의 엽조직 질소함유량이 1990년 보다 8% 증가한 것으로 나타났다. 따라서, 잔디조성후 경과기간에 따라 연간 시비량을 조절할 필요가 있으며, 특히 새로 조성된 잔디밭과 조성된 지 어느 정도 지난 기존 잔디밭간에 차별화된 관리프로그램이 필요한 것으로 판단되었다.

잔디관리에서 답압이 가중되는 정도에 따라 지역별로 장기간 차별화된 관리 접근을 해야하고, 정기적으로 토양 및 엽분석을 실시해서 시비프로그램에 활용하는 것이 필요하다 하겠다. 본 연구결과 나타난 잔디관리 요인간 상호작용효과는 잔디관리시 여러 가지 관리방법에 따른 효과를 입체적으로 분석해서 해당 골프장 현실에 적합한 통합적인 잔디관리(integrated turfgrass management)의 필요성을 제시한다고 할 수 있겠으며, 또한 답압가중 정도에 따른 잔디관리요인간의 반응효과 차이는 향후 무답압 지역에서 실시된 연구결과를 답압을 받고 있는 경기장 및 골프장 등의 잔디밭에 적용할 경우에는 주의깊게 데이터 활용을 해야 되리라고 사료되었다.

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