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EFFECT OF N-FORM ON MACRONUTRIENT AND MICRONUTRIENT CONCENTRATION AND UPTAKE OF CREEPING BENTGRASS[1]

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ABSTRACT: Nitrogen-form effect on nutrient uptake and the subsequent concentration of nutrients in turfgrass plant tissue has not been thoroughly investigated. This study evaluated the effects of clipping regime and N-form on the tissue concentration of macronutrients and micronutrients and macronutrient uptake in 'Penncross' creeping bentgrass *(Agrostis palustris* Huds.). Turfgrass plugs were grown under greenhouse conditions in a modified Hoagland's solution with a combination of three nutrient solutions (100% $N0_3$\ 100% NH_4^+, and 50:50 ratio of NH_4^+:$N0_3$") and two cutting regimes (cut and uncut). Concentrations of macronutrients and micronutrients were determined for shoot, root and verdure. Nutrient uptake was determined weekly. Uncut $N0_3$'-treated plants accumulated higher concentrations of K, Ca, Mg, B and Cu in the shoot tissue; P, K, Ca, Mg, B, Cu, Mn and Zn in the root tissue; and P, Ca, Mg, B, Fe and Mn in the verdure compared to uncut NtV-treated plants. Nitrate uptake was greater with uncut $N0_3$'-treated plants than was NH_4^+ absorption with uncut NH/-treated plants. Plants grown with the uncut 50:50 treatment adsorbed more NH_4^+ than $N0_3$

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Plants grown with the uncut N0$_3$' and 50:50 treatments adsorbed higher amounts of P, K, and Ca compared to the NH4 treatment. The cut N0$_3$"-treated plants accumulated higher concentrations of K in the shoot tissue; P, Ca, Mg, B, Cu, Fe and Mn in the root tissue; and B in the verdure than did the cut NJV-treated plants. Cut N0$_3$"-treated plants adsorbed less N0$_3$" than did cut NJV-treated plants adsorbed NH4. The cut 50:50 treatment adsorbed more NH4 than N0$_3$'. Plants grown with N0$_3$' and 50:50 treatments, under both cutting regimes, resulted in higher concentrations of most macro- and micronutrients and greater nutrient uptake compared to the NIV-treated plants.

INTRODUCTION

The form of nitrogen, ammonium or nitrate, affects the uptake of other nutrients by plants and plays a role in the concentration of nutrients found in plant tissue (Cox and Reisenauer, 1973; Haynes and Goh, 1978). Ammonium competes with other cations during uptake and, as the ammonium level increases, cation uptake decreases in most plant species. In contrast, nitrate generally stimulates cation uptake and inhibits anion uptake (Cox and Reisenauer, 1973; Jackson and Williams, 1968). Ammonium also suppresses nitrate uptake and is particularly detrimental to Ca, Mg and K uptake (Ajayi et al., 1970; Jacobsen and Swanback, 1933; Tromp, 1962). High ammonium levels can increase the uptake of P and S in certain plants (Amon, 1939; Blair et al., 1970).

Cox and Reisenauer (1973) found increasing levels of N0$_3$" were associated with increased Ca, K and Mg uptake while increasing levels of NH/ resulted in decreased Ca, K and Mg uptake in wheat *(Triticum aestivwn* L.). This resulted in higher Ca, K and Mg concentrations in the shoots of the N0$_3$"-treated plants. However, they found lower P concentrations in the NIV-treated plants. Others have reported higher concentrations of Ca, K and Mg in plants grown with high N0$_3$' levels compared to plants grown with high NIV levels (Anion, 1939; Blair et al., 1970; Borys et al., 1970). Plants grown with high N0$_3$' levels can sustain growth with lower concentrations of P (Asher and Loneragan, 1967; Bennett et al., 1964; Blair et al., 1970).

Effects of N-form on micronutrient tissue concentration has been suggested in various stuthes. Arnon (1937) found that NH4-treated plants required increased amounts of applied micronutrients in comparison to $N0_3$'-treated plants. Small additions of Cu and Mn to NH4 solutions resulted in increased root and shoot growth of barley, while additions to $N0_3$" solutions did not affect plant growth. Arnon (1939) reported that additional applications of Mn increased the growth of NH4-treated plants. Nitrate-treated plants adsorbed more Mn and resulted in higher Mn concentrations in the root, although overall growth was not affected by the addition of Mn. He stated that when NH_4^+ was the sole nitrogen source, the supply of micronutrients may need to be increased to maintain plant growth.

Considerably less research has been done on micronutrient concentration in turfgrass plant tissue than on macronutrient stuthes (Love, 1962; Christians et al., 1981, Waddington et al., 1972). The effects of N-form and adequate micronutrient levels for turfgrasses under field conditions have not been determined. Most stuthes report micronutrient tissue data that involved N, P, and K fertilizer stuthes in which the micronutrients were sometimes included in the fertilizer (Markland and Roberts, 1969; Waddington et al., 1972). Therefore, some treatments did not receive any micronutrients. In most of these stuthes, there were no supplemental applications of micronutrients and the concentration of micronutrients in the turfgrass plants was generally in the low to medium end of the sufficiency range given for turfgrasses (Jones, 1980; Jones et al., 1991). Christians et al. (1981), working with creeping bentgrass on a calcareous sand green, reported that Mn may have been limiting growth at high rates of N and K. These workers suggested that certain micronutrients might be a limiting factor for the growth of creeping bentgrass under conditions present in the sand mixture of the greens. They suggested that the correction of micronutrient deficiencies on greens might actually lower nitrogen requirements.

Creeping bentgrass, commonly used in putting greens, undergoes constant mowing, which directly affects shoot and root growth of the plant. Harrison (1934) investigated the effect of mowing and nitrogen fertilization on Kentucky bluegrass *(Poa pratensis* L.) and reported that it was possible to influence the relative amounts and proportions of various plant parts by changing the nitrogen supply and the mowing regime. Generally, clippings are removed when creeping bentgrass is mowed. This practice removes nutrients that otherwise might be released to the soil for further utilization by the plant (Beard, 1973). Thus, the application rate of macro- and micronutrients may need to be increased to replace nutrients that are removed by clipping (Beard, 1973; Noer, 1959). Therefore, since creeping bentgrass is subjected to constant mowing, the uptake of macro- and micronutrients affected by mowing needs to be determined in order to project fertilizer applications.

The effect of N-form and clipping regime on nutrient uptake and subsequent nutrient concentrations in the plant tissue of creeping bentgrass needs further study in order to maximize nutrient utilization. Therefore, the objectives of this study were to determine the effects of clipping and N-form on macro- and micronutrient uptake and on the concentration of macronutrients and micronutrients in creeping bentgrass.

MATERIALS AND METHODS

Plugs of creeping bentgrass (10.2 cm diameter by 8.4 cm deep) were taken from an established 'Penncross' creeping bentgrass putting green at the University of Georgia turfgrass plots in Athens, GA. Soil was washed from all plugs and the roots were cut 2 cm below the thatch layer. Each plug was placed in a separate 18-liter solution culture vessel containing 14 liters of water. The water was changed weekly for three weeks after which time the nutrient solution treatments were initiated.

The essential elements were applied as a modified Hoagland's solution. The nutrient solution treatments were 100% NH4, 100% $N0_3$', and a 50:50 ratio of NH_4:$N0_3$. The N concentration was 50 mg N kg$^{'1}$ with the N sources being $(NH_4)_2S0_4$ and $Ca(N0_3)_2$ • $4H_zO$ for the NH_4^+ and $N0_3$' treatments, respectively. The 50:50 treatment received 25 mg N kg$^{'1}$ from each treatment of $(NH_4)_2S0_4$ and $Ca(N0_3)_2$ • $4H_20$. All treatments received P and K as 19 mg K kg$^{'1}$ and 15 mg P kg$^{'1}$ from KH2PO4 and 31 mg K kg$^{'1}$ from K_2S0_4. The $N0_3$' and 50:50 treatments received 72 and 36 mg Ca kg$^{''1}$, respectively, from $Ca(N0_3)$ $4H_20$. The 50:50 and NH/ treatments received 14 mg Ca kg$^{'1}$ from $CaCl_2$. The 50:50 treatment received an additional 22 mg Ca kg$^{'1}$ from $CaS0_4$" $2H_20$ and the NH_4^+ treatment received 58 mg Ca kg$^{'1}$ from the same source to provide a total of 72 mg Ca kg$^{''1}$ for each of these treatments. The $N0_3$" treatment received 9 mg Mg kg$^{'1}$ from $MgCl_2$ $6H_20$ and 9 mg Mg kg$^{'1}$ from $MgS0_4$ $7H_20$, while the other treatments received 18 mg Mg kg$^{'1}$ from $MgS0_4$ $7H_20$. All treatments contained the following micronutrient concentrations: 0.25 mg B kg$^{'1}$ as H_3B0_3, 0.25 Mn as $MnCl_2$ • $4H_20$, 0.02 mg Cu kg$^{:i}$ as $CuS0_4$ • $5H_2O_t$ 0.01 mg Mo kg$^{'1}$ as $Mo0_3$, 0.5 mg Zn kg^1 as $ZnS0_4$ • $7H_20$, and 5 mg Fe kg$^{''1}$ as Fe-EDTA. Chloride was present at 25 mg CI kg$^{''1}$ provided by $CaCl_2$ and $MgCl_2$ $6H_20$.

Transpirational losses from the solutions were replaced weekly with deionized water. Nutrient solution samples were taken weekly for the new and old nutrient solutions of each solution and analyzed for differences in the initial and ending values of each essential element to determine weekly nutrient uptake values. Ammonium and nitrate values were determined using a Flow Injection Analyzer (LACHAT), while all other essential elements were analyzed using an inductively coupled argon plasma (ICAP) emission spectrometer (Thermo Jarrell Ash ICAP 9000, Jarrell-Ash, Franklin, MA 02038).

The initial pH of the solutions was 6.4 to 6.7 and was not adjusted during the week. The pH of the new and old solutions were taken to ascertain pH changes for each treatment. The pH change (new solution pH-old solution pH) for the treatments were: uncut $N0_3$" (6.6-7.0); cut $N0_3$' (6.6-6.5); uncut NH_4^+ (6.6-3.8); cut NH4 (6.5-6.4); uncut 50:50 (6.5-4.2); cut 50:50 (6.6-6.6).

The nutrient solution treatments were split into two mowing regimes, cut and uncut. Half of the plants were cut twice weekly and maintained at a height of 1 cm (cut), while the other half of the plants were not cut until final harvest (uncut). All plants were harvested at the end of a 6 week treatment period. The roots were cut as close to the thatch layer as possible. Final shoot clippings were taken for both the uncut and cut plants with the remaining material being the verdure. Shoot, root, and verdure were dried in a forced hot air oven at 70° C for 72 hr. Separate plant parts were then ground in a Wiley mill (Arthur H. Thomas Co., Philadelphia, PA 19105) to pass a 2-mm screen. Kjeldahl N was determined for each separate plant part and other essential elements were analyzed by ICAP following dry-ashing.

The experiment was conducted as a randomized complete block design with three replications. The data was subjected to analysis of variance utilizing the GLM procedure of SAS, and LSDs were performed to determine mean separation (SAS, Version 6, SAS Institute, Cary, NC). Significant differences were those that occurred at the $a=0.05$ level ($P < 0.05$). Data for uncut and cut plants were analyzed separately. The shoot concentration data for the uncut plants were based on the final harvest dry matter, while the shoot concentrations for the cut plants were based on dry matter for the final week.

RESULTS AND DISCUSSION

Macronutrient Concentration of Uncut Plants

Shoots: Nitrate-treated plants were significantly higher in concentrations of K, Ca, and Mg in the shoot tissue in comparison to the NlV-treated plants, and were higher in concentration of Ca compared to plants of the 50:50 treatment (Table 1). This finding supports other reported work in which N0$_3$"-treated plants provided higher concentrations of K, Ca, and Mg in shoots compared to NTV-treated plants (Arnon, 1939; Blair et al., 1970; Cox and Reisenauer, 1973).

Although data were not statistically different, the N concentration of the NlV-treated plants was slightly higher than the N0$_3$' and 50:50-treated plants.

Table 1. Effect of N-form on the Concentration of Macronutrients in Creeping Bentgrass Shoot, Root and Verdure tissue.

	Macronutrient				
N-form Ratio	N	P	K	Ca	Mg
Shoot	g 100 kg^{-1}				
NO_3^--Uncut	3.39	0.63	3.82 a	0.83 a	0.33 a
NH_4^+-Uncut	3.43	0.63	3.24 b	0.32 c	0.26 b
50:50-Uncut	3.30	0.63	3.48 ab	0.47 b	0.30 ab
LSD α=0.05	NS	NS	0.38	0.11	0.06
NO_3^--Cut	4.83	0.64	3.15 a	0.89	0.44
NH_4^+-Cut	5.09	0.66	2.81 b	0.76	0.43
50:50-Cut	5.10	0.68	2.65 b	0.96	0.38
LSD α=0.05	NS	NS	0.27	NS	NS
Root	g 100 kg^{-1}				
NO_3^--Uncut	2.42	2.31 a	1.25 a	4.11 a	0.37 a
NH_4^+-Uncut	2.41	0.74 b	0.57 b	0.16 b	0.05 c
50:50-Uncut	2.17	0.90 b	1.27 a	0.42 b	0.17 b
LSD α=0.05	NS	0.65	0.50	1.53	0.06
NO_3^--Cut	1.74	2.62 a	0.66 a	3.84 a	0.24 a
NH_4^+-Cut	1.46	0.88 b	0.36 b	0.75 c	0.09 c
50:50-Cut	1.58	1.06 b	0.34 b	1.13 b	0.12 b
LSD α=0.05	NS	0.18	0.24	0.25	0.02
Verdure	g 100 kg^{-1}				
NO_3^--Uncut	0.83 b	0.48 a	0.50	3.20 a	0.42 a
NH_4^+-Uncut	1.44 a	0.17 b	0.53	0.62 b	0.10 b
50:50-Uncut	0.96 ab	0.23 b	0.55	1.44 b	0.56 a
LSD α=0.05	0.60	0.22	NS	1.19	0.30
NO_3^--Cut	0.99	0.35	0.51	1.23	0.19
NH_4^+-Cut	0.95	0.24	0.67	0.88	0.22
50:50-Cut	1.14	0.25	0.57	0.88	0.22
LSD α=0.05	NS	NS	NS	NS	NS

Means within columns for a cutting regime followed by the same letter are not significantly different according to LSD mean separation test at ct=0.05.

This is similar to other stuthes in which plants treated with a higher ratio of NH_4^+ to $N0_3$' provided greater N concentrations than those receiving a higher $N0_3$' to NH_4^+ ratio (Blair et al., 1970; Cox and Reisenauer, 1973). In addition, the NH4 treated plants yielded less dry matter accumulation.

In the present study, there were no differences between the P concentration in the shoot tissue of plants grown with either the 100% $N0_3$' or 100% NH/ treatments. Several stuthes have reported increased P concentrations in plants grown with high NH4 levels compared to high $N0_3$" levels (Arnon, 1939; Blair et al., 1970; Bennett et al., 1964). These results suggest that N-form effects on P accumulation in the tissue may be related to availability of P in the soil versus a direct influence on uptake.

Roots: Plants grown with 100% $N0_3$" were significandy higher in concentrations of P, Ca, and Mg in the root tissue than were the other treatments (Table 1). Plants grown with either the 100% $N0_3$' or 50:50 treatments had higher K concentrations man those of me 100% NH4 treatment. Several stuthes have reported higher concentrations of K, Ca, and Mg in the roots of plants grown with $N0_3$" compared to those grown with $NH4^+$ (Blair et al, 1970; Cox and Reisenauer, 1973). Blair et al. (1970) reported higher Ca levels in roots of corn *(Zea mays L.)* for $N0_3$"-treated plants. In the present study, mere were significandy higher Ca concentrations in the roots of the $N0_3$-treated plants compared to the 100% NH_4^+ and 50:50 treatments.

The higher P concentration in the $N0_3$"-treated plants compared to me NlV-treated plants was in contrast to what has generally been reported by others (Bennett et al., 1964; Blair et al., 1970). However, Cox and Reisenauer (1973) reported higher P concentrations in the roots of barley grown with 100% $N0_3$" versus 100% NH/- Bennett et al. (1964) reported higher P concentre i'ons in the root tissue of corn grown wim 100% NIV versus tiiat grown wim 100% $N0_3$". Blair et al. (1970) reported significandy greater P concentrations in com roots of $NH,^+$-treated plants compared to $N0_3$'-rreated plants. Phosphorus accumulation by the plant may be more dependent on P availability in the soil man on P uptake by me plant

Verdure: The concentration of N in the verdure tissue of the NH4-treated plants was significandy higher compared to plants treated with 100% $N0_3$" (Table 1). The 100% $N0_3$' treatment produced significandy higher P and Ca concentrations compared to the other treatments. Plants grown with the 100% $N0_3^-$ and 50:50 treatments resulted in significantly higher Mg concentrations than was seen in those grown with 100% NH_4^+.

Micronutrient Concentration of Uncut Plants

Shoots: There were significant differences between the 100% $N0_3^-$ and the 100% NH_4^+ treatments for B and Cu concentration in the shoot tissue, while the 50:50 treatment was significantly different from bom treatments for B concentration (Table 2). The Fe concentration in shoot tissue of the 100% NH_4^+ and 50:50 treatments was not statistically different, but the 50:50 treatment tissue had a higher concentration than that of the 100% $N0_3^-$ treatment. The 100% $N0_3^-$ treatment resulted in a higher Zn concentration than did the 50:50 treatment.

The concentration of micronutrients in the shoot tissue of plants with the N-form treatments was within or exceeded the sufficiency range for each individual micronutrient (Jones et al., 1991). In this study, micronutrients were supplied in equal quantities to all of me N-form treatments. Therefore, any plant growth response should not have been limited by a micronutrient deficiency. Arnon (1937; 1939) reported increases in shoot growth with additions of Cu and Mn to NH_4^+-treated plants even though the Mn concentration of these plants was less that of the $N0_3^-$-treated plants. He found NH_4^+-treated plants required a greater supply of micronutrients than did $N0_3^-$-treated plants. Furthermore, he suggested that the supply of micronutrients available to the plant may be insufficient for proper plant growth when NH_4^+ is the sole nitrogen source. In the present study, there were no differences for Mn concentration among the treatments, while Cu concentration was highest with the 100% $N0_3^-$-treated plants. Data reported here suggests that these nutrients would be obtained by the plant due to availability in the soil as opposed to uptake by the plant.

Roots: Plants grown with 100% $N0_3^-$ were significantly higher for concentrations of B, Cu, Mn, and Zn in the root tissue compared to plants grown with the other treatments (Table 2). The 100% NH_4^+ and 50:50 treatments accumulated a significantly higher Mo concentration. The data for Cu and Mn concentration is

Table 2. Effect of N-form on the Concentration of Micronutrients in Creeping Bentgrass Shoot, Root and Verdure Tissue.

	Micronutrient					
N-form Ratio	B	Cu	Fe	Mn	Mo	Zn
Shoot			mg kg^{-1}			
NO_3^--Uncut	15.26 b	14.70 a	227 b	322	0.58	143 a
NH_4^+-Uncut	10.03 c	8.72 b	260 ab	304	0.47	122 ab
50:50-Uncut	18.33 a	8.50 b	297 a	233	0.48	97 b
LSD α=0.05	2.31	0.92	67	NS	NS	27
NO_3^--Cut	27.27	18.31 a	255 b	712	1.26 a	193 b
NH_4^+-Cut	18.84	15.81 ab	719 a	1170	1.20 a	281 a
50:50-Cut	27.32	12.55 b	626 ab	843	0.68 b	182 b
LSD α=0.05	NS	3.99	455	NS	0.47	71
Root			mg kg^{-1}			
NO_3^--Uncut	17.81 a	46.38 a	26,617	1835 a	1.02 b	1298 a
NH_4^+-Uncut	7.81 b	9.13 b	36,980	214 b	2.77 a	291 c
50:50-Uncut	8.80 b	10.10 b	30,287	359 b	2.39 a	518 b
LSD α=0.05	7.36	4.81	NS	210	1.17	182
NO_3^--Cut	20.44 a	65.07 a	51,875 a	6570 a	1.60	1586
NH_4^+-Cut	9.73 b	28.81 b	35,336 b	3310 b	1.53	1505
50:50-Cut	11.49 b	32.70 b	39,692 ab	4623 b	1.57	1028
LSD α=0.05	2.32	17.71	13,806	1585	NS	NS
Verdure			mg kg^{-1}			
NO_3^--Uncut	39.95 a	19.33	4358 a	1111 a	0.59	203 ab
NH_4^+-Uncut	4.14 b	14.91	1570 c	384 b	0.51	122 b
50:50-Uncut	17.71 b	16.25	2926 b	755 ab	0.58	265 a
LSD α=0.05	20.48	NS	1353	590	NS	123
NO_3^--Cut	14.55 a	10.72	2232	1626	0.44	194
NH_4^+-Cut	7.34 b	8.19	1512	992	0.47	214
50:50-Cut	10.52 ab	7.96	1658	842	0.55	172
LSD α=0.05	4.71	NS	NS	NS	NS	NS

Means within columns for a cutting regime followed by the same letter are not significantly different according to LSD mean separation test at α=0.05.

similar to the findings of Arnon (1937). He reported increased root growth with additions of Mn to NH_4^+-treated barley *(Hordewn vulgare* L.) plants compared to those NH_4^+-treated plants receiving no Mn, although the Mn concentration of these plants was less that of the $N0_3^-$-treated plants. The addition of Mn to $N0_3^-$ treated plants showed less growth response. The addition of Cu to NH_4^+-treated plants increased root dry weight (180%) compared to the NH_4^+-treated plants not receiving Cu.

Verdure: The plants of the 100% $N0_3^-$ treatment were significantly higher for concentrations of B, Fe and Mn in the verdure compared to plants of the 100% NH_4^+ treatment (Table 2). The 50:50 treatment was significantly different from the 100% $NH,^+$ treatment for Zn concentration.

Macronutrient Concentration of Cut Plants

Shoots: The 100% $N0_3^-$ treatment resulted in a significantly higher concentration of K in the shoot tissue compared to the other treatments (Table 1). This was the only significant difference among the treatments regarding macronutrient concentration. Although data were not statistically different, plants of both the 50:50 and 100% NH_4^+ treatments had slightly higher N concentrations than did plants of the 100% $N0_3^-$ treatment. Similar results have been reported by Markland and Roberts (1969).

Roots: The 100% $N0_3^-$ treatment produced significantly higher concentrations of P, K, Ca and Mg in the root compared to the other treatments (Table 1). The 50:50 treatment was significantly different from the 100% NH_4^+ treatment for Ca and Mg concentrations. Similar results for Ca, K, and Mg concentrations have been reported by others (Arnon, 1939; Blair et al., 1970; Cox and Reisenauer,

Verdure: There were no significant differences among the 100% $N0_3^-$ 100% NH_4^+, and 50:50 treatments for the concentration of any of the macronutrients in the verdure (Table 1). The concentration of each macronutrient in the verdure was lower for each treatment relative to the macronutrient concentrations present in the shoot and root tissue. In contrast to macronutrient concentration in the verdure, the total amount of each macronutrient in the verdure was higher than the total amount of each macronutrient present in the shoot and root tissue (Unpublished data). The total amount of each macronutrient is based on both the concentration and dry matter accumulation of the particular plant part. Therefore, since verdure dry matter accumulation was greater than either shoot or root dry matter accumulation, the total macronutrient amount present in the verdure was greater than the total amount found in either the shoot or root (Unpublished data).

Micronutrient Concentration of Cut Plants

Shoots: The 100% $N0_3^-$ and 100% NH_4^+ treatments were significantly different in concentrations of Fe and Zn in the shoot tissue (Table 2). The 100% $N0_3^-$ and 50:50 treatments were significantly different for concentrations of Cu and Mo. Although there were no significant differences for Mn among the treatments, the 100% NH_4^+ treatment had the highest Mn concentration. This treatment had 64% and 39% higher Mn concentrations than the 100% $N0_3^-$ and 50:50 treatments, respectively. In contrast to this data, Arnon (1939) reported significantly higher concentrations of Mn in $N0_3^-$-treated barley.

Roots: The 100% $N0_3^-$ treatment was significantly higher for concentrations of B, Cu and Mn in the root tissue compared to the other treatments (Table 2). Although not significantly different from the 50:50 treatment, the 100% NH_4^+ treatment provided the lowest concentrations for each micronutrient except Zn. Arnon (1939) reported significant differences in the Mn concentration of roots of barley plants treated with $N0_3^-$ and NIL,*. Increased Mn levels in the nutrient solution resulted in a large increase in root Mn concentration in the $N0_3^-$-treated plants but only a small increase in the root Mn concentration in the NH_4^+-treated plants. He concluded that the $N0_3^-$-treated plants had a much greater adsorptive capacity for Mn than had the NH_4^+-treated plants and accumulated much greater amounts of Mn without harmful effects. In the present study, the $N0_3^-$-treated plants had 98% higher Mn concentration in the root tissue compared to the roots of the NIV-treated plants.

Verdure: Boron concentration was significantly higher in the $N0_3^-$ -treated plants than in plants treated with 100% NH_4^+ (Table 2). Although data were not significantly different, the $N0_3^-$-treated plants tended to result in the highest concentrations while the NH_4^+-treated plants tended to result in the lowest. The only exceptions were for Mo and Zn, which were higher for plants grown under the 50:50 and 100% NH_4^+ treatments, respectively.

Macronutrient Uptake of Uncut Plants

Nitrate and Ammonium: Nitrate uptake by the NO_3^--treated plants increased for each week of the study (Table 3). Ammonium uptake by the NH_4^+-treated plants increased through week 3 and decreased at week 4. Uptake of NH_4^+ was greater than uptake of NO_3^- for the 50:50 treatment during the first five weeks. The 50:50 treatment exhibited a weekly increase in the uptake of NO_3^- while uptake of NH_4^+ increased through week 4, when it decreased slightly. The NO_3^--treated plants adsorbed considerably more NO_3^- in the final three weeks than in the first three weeks. The greater plant growth of the NO_3^--treated plants explains the increase in NO_3^- uptake later in the study. The decreased uptake of NH_4^+ and less plant growth was possibly caused by a decrease in carbohydrate supply and continuing NH_4^+ detoxification by the NH_4^+-treated plants over time (Barker and Mills, 1980).

Phosphorus: Phosphorus uptake was slightly higher for the 100% NO_3^- and 50:50 treatments than for the 100% NH_4^+ treatment for the first three weeks, but only significantly higher for the 100% NO_3^- treatment at week 1 (Table 4). For weeks 4 through 6, P uptake was significantly higher for both the 100% NO_3^- and 50:50 treatments compared to the 100% NH_4^+ treatment. This result suggests that N-form influenced P uptake after three weeks. This data suggests that P in the soil may be affected more by P availability instead of P uptake by the plant.

Potassium: Potassium uptake increased from week 1 to week 2 and then decreased considerably at week 3 for each of the treatments (Table 5). After week 3, there was an increase in K uptake for both the 100% NO_3^- and 50:50 treatments and uptake was significantly higher for both treatments compared to the 100% NH_4^+ treatment. The data suggests that N-form influenced K uptake after three weeks.

Calcium: Generally, for all treatments, Ca uptake followed a 2-week pattern of increased uptake followed by a decrease (Table 6). The 100% NO_3^- treatment had the highest Ca uptake while the 100% NH_4^+ treatment had the lowest. After three weeks, Ca uptake increased considerably for the NO_3^- treatment. Overall, Ca uptake appeared to be enhanced under the 100% NO_3^- treatment, and to a lesser

Table 3. Weekly Uptake of NO_3^- and NH_4^+ in Response to N-form.

N-form ratio	Week 1	2	3	4	5	6
	NO_3^-					
	mg L^{-1}					
NO_3^--Uncut	3.67 a	8.45a	20.07a	31.26a	42.98a	47.54a
NH_4^+-Uncut	0.10 b	0.02c	0.38c	0.00c	0.96c	0.00c
50:50-Uncut	1.44 ab	3.02b	10.51b	15.27b	20.04b	25.10b
LSDα=0.05	2.75	1.02	1.75	4.78	5.93	2.82
NO_3^--Cut	4.22 a	2.72a	4.53a	2.28	0.81	0.44
NH_4^+-Cut	0.07 b	0.00b	0.16b	0.00	0.32	0.00
50:50-Cut	1.46 b	0.51b	1.34b	1.11	0.00	0.00
LSDα=0.05	2.68	1.15	2.27	NS	NS	NS
	NH_4^+					
	mg L^{-1}					
NO_3^--Uncut	0.00 b	0.06 b	0.00 c	0.00 b	0.02 c	0.05 c
NH_4^+-Uncut	6.39 a	9.39 a	20.43 a	18.85 a	24.67 a	15.15 b
50:50-Uncut	5.17 a	8.23 a	15.76 b	21.56 a	20.09 b	24.88 a
LSD α=0.05	1.39	2.21	1.12	4.65	0.35	3.69
NO_3^--Cut	0.00 b	0.00 b	0.00 b	0.00	0.00 b	0.07 c
NH_4^+-Cut	6.32 a	3.44 a	6.74 a	1.48	2.04 a	3.08 a
50:50-Cut	4.81 a	3.26 a	4.03 ab	1.66	1.14 ab	1.89 b
LSD α=0.05	1.60	1.36	4.39	NS	1.50	1.19

Means within columns for a cutting regime followed by the same letter are not significantly different according to LSD mean separation test at $\alpha = 0.05$.

Table 4. Weekly Uptake of Phosphorus in Response to N-form.

N-form ratio	Week 1	2	3	4	5	6
	mg L^{-1}					
NO_3^--Uncut	3.17 a	3.42	3.08	10.49 a	10.05 a	11.34 a
NH_4^+-Uncut	2.22 b	3.05	0.00	2.36 b	0.28 c	3.17 c
50:50-Uncut	2.57 b	3.20	0.00	6.69 a	5.13 b	8.44 b
LSD α=0.05	0.45	NS	NS	3.88	1.79	1.89
NO_3^--Cut	3.22 a	2.48	0.00	1.90	0.25	1.64 a
NH_4^+-Cut	2.42 b	1.90	0.00	0.46	0.00	1.09 b
50:50-Cut	2.65 b	2.21	0.16	0.63	0.13	1.25 ab
LSD α=0.05	0.39	NS	NS	NS	NS	0.50

Means within columns for a cutting regime followed by the same letter are not significantly different according to LSD mean separation test at $\alpha = 0.05$.

Table 5. Weekly Uptake of Potassium in Response to N-form.

N-form ratio	Week 1	2	3	4	5	6
	mg L^{-1}					
NO_3^--Uncut	4.48 a	12.17	4.81	32.40 a	36.93 a	50.00 a
NH_4^+-Uncut	3.50 ab	13.97	0.25	17.17 b	3.03 b	22.05 b
50:50-Uncut	3.13 b	13.92	1.94	36.77 a	35.60 a	50.00 a
LSD α=0.05	1.24	NS	NS	12.81	10.06	5.45
NO_3^--Cut	4.54	6.57	0.00	4.28	0.00	8.15
NH_4^+-Cut	3.28	6.25	0.00	1.91	0.00	8.17
50:50-Cut	4.00	[illegible]	0.00	3.15	0.00	7.79
LSD α=0.05	NS	NS	NS	NS	NS	NS

Means within columns for a cutting regime followed by the same letter are not significantly different according to LSD mean separation test at α = 0.05.

Table 6. Weekly Uptake of Calcium in Response to N-form.

N-form ratio	Week 1	2	3	4	5	6
	mg L^{-1}					
NO_3^--Uncut	0.75	5.92 a	4.12	28.39 a	9.18 a	24.56 a
NH_4^+-Uncut	0.00	1.31 b	0.00	4.25 c	0.00 b	3.46 c
50:50-Uncut	0.00	3.10 b	0.00	19.16 b	0.86 b	16.00 b
LSD α=0.05	NS	2.15	NS	9.11	1.62	6.48
NO_3^--Cut	0.90 a	3.43	0.00	6.34	0.00	3.42
NH_4^+-Cut	0.07 b	1.08	0.00	2.69	0.00	3.82
50:50-Cut	0.00 b	1.38	0.00	3.06	0.00	3.79
LSD α=0.05	0.63	NS	NS	NS	NS	NS

Means within columns for a cutting regime followed by the same letter are not significantly different according to LSD mean separation test at α = 0.05.

extent, the 50:50 treatment, while Ca uptake was depressed under the 100% NH_4^+ treatment. Further evidence for this is indicated by both the 100% $N0_3^-$ and 50:50 treatments resulting in higher Ca concentrations than the 100% NH_4^+ treatment for each separate plant part.

Table 7. Weekly Uptake of Magnesium in Response to N-form.

N-form ratio	Week 1	2	3	4	5	6
	mg L^{-1}					
NO_3^--Uncut	1.21	2.46	0.51	5.25	0.48	6.78 a
NH_4^+-Uncut	0.81	2.39	0.00	1.74	0.00	2.78 b
50:50-Uncut	0.86	2.43	0.00	5.19	0.23	5.14 ab
LSD α=0.05	NS	NS	NS	NS	NS	3.93
NO_3^--Cut	1.25	1.83	0.00	1.35	0.00	1.55
NH_4^+-Cut	1.02	1.54	0.00	0.52	0.00	1.77
50:50-Cut	1.16	2.07	0.00	0.75	0.00	1.70
LSD α=0.05	NS	NS	NS	NS	NS	NS

Means within columns for a cutting regime followed by the same letter are not significantly different according to LSD mean separation test at $\alpha = 0.05$.

Magnesium: There were no statistical differences among treatments for Mg uptake, except for week 6 (Table 7). Although data were not significantly different, plants of the 100% $N0_3^-$ treatment tended to adsorb the highest amount of Mg while plants of the 100% NH_4^+ treatment tended to adsorb the lowest amount of Mg.

Micronutrient Uptake of Uncut Plants

Generally, uptake of various micronutrients by plants of the three treatments was significantly different among treatments for only a few weeks. Boron uptake was higher for the 100% $N0_3^-$ and 50:50 treatments during weeks 4 and 6. Copper uptake was highest for week 5 with the 100% $N0_3^-$ treatment. The 100% $N0_3^-$ treatment had the highest Fe uptake for weeks 1, 2 and 4; the highest Mn uptake for weeks 2 through 6; and the highest Zn uptake for weeks 2, 3, 5 and 6. This result suggests that N-form influences the uptake of micronutrients, although there were no patterns. When significant treatment differences did occur, they generally occurred after three weeks.

Macronutrient Uptake of Cut Plants

Nitrate and Ammonium: Ammonium uptake was higher man $N0_3^-$ uptake when the N-forms were provided in equal amounts under the 50:50 treatment (Table 3). Several stuthes have reported that NH_4^+ depresses $N0_3^-$ uptake, and NH_4^+ uptake generally exceeds $N0_3^-$ uptake when the two are present in equal amounts (Weissman, 1951; Fried et al., 1965). There was an increase and then a decrease in the uptake of $N0_3^-$ and NH_4^+ by the 50:50 treatment every two weeks resulting in zero $N0_3^-$ uptake during the last two weeks but continued NH_4^+ uptake. The NH_4^+-treated plants absorbed more NH_4^+ the first three weeks than the $N0_3^-$-treated plants adsorbed $N0_3^-$

Phosphorus: Phosphorus uptake was highest for the 100% $N0_3^-$ and 50:50 treatments with the only significant differences for P uptake occurring at weeks 1 and 6 (Table 4). Phosphorus uptake was lowest at weeks 3 through 5 and then increased at week 6 for all treatments.

Potassium: There were no significant differences among treatments for K uptake during any week (Table 5). There was an increase in K uptake from week 1 to week 2 and then a decrease at week 3 to no K uptake for all treatments. After week 3, all treatments experienced an increase in uptake at week 4 followed by a decrease to zero at week 5. This was followed by an increase at week 6 to the highest levels of K uptake for each treatment. This indicates that K uptake was somewhat cyclic.

Calcium: Although the actual amounts of Ca uptake were much lower for the plants of the cut treatments compared to the uncut plants, the pattern of an increase and then a decrease in Ca uptake over a 2-week period occurred, as was the case with the uncut plants (Table 6). Calcium uptake was not significantly different for any treatments, except at week 1.

Magnesium: There were no statistical differences among treatments for Mg uptake over the six weeks (Table 7). The uptake of Mg increased from week 1 to week 2 and then decreased at week 3 to zero for all treatments. There was a slight increase in uptake at week 4 followed by no uptake at week 5.

Micronutrient Uptake of Cut Plants

There were few significant differences among treatments for uptake of micronutrients by the cut plants. At week 1, the $N0_3^-$ treatment had higher Fe uptake than did the 50:50 treatment. Manganese uptake was higher for the 50:50 and 100% NIL,* treatments at week 3. Molybdenum uptake was higher for the 50:50 and 100% $N0_3^-$ treatments at week 5.

CONCLUSIONS

The form of nitrogen utilized in a fertility program can have an impact on the macronutrient and micronutrient concentration and the macronutrient uptake of creeping bentgrass. In general, when 50% or more of the nitrogen treatment of both uncut and cut plants of creeping bentgrass was $N0_3^-$-N (100% $N0_3$ and 50:50 treatments), plants showed higher concentrations of most macronutrients and micronutrients in the shoots, roots and verdure compared to those plants treated with only NH_4^+. The macronutrient and micronutrient concentrations were highest for the $N0_3$-treated plants and lowest for the NH_4^+-treated nlants.

Generally, uncut and cut creeping bentgrass plants grown with either the 100% $N0_3$ or the 50:50 treatment had higher uptake of P, K, Ca, and Mg than did uncut and cut plants grown with the 100% NH_4^+ treatment. Creeping bentgrass plants grown with the uncut and cut 50:50 treatments adsorbed more NH_4^+ than $N0_{3-}$ In general, the uptake values of P, K, Ca, and Mg for the 50:50 treatments closely resembled the uptake values of the $N0_3$" treatments under both cutting regimes.

The 100% $N0_{3-}$ and 50:50 treatments, under both cutting regimes, produced a more balanced nutrient level concentration for the macronutrients and micronutrients in the plant than did the 100% NH_4^+ treatments. The uncut plants took up greater quantities of each macronutrient than did the cut plants under their respective N-form treatments. The cut plants took up small quantities of each nutrient but were able to continue growing. This indicates that under continuous cutting these plants required small amounts of each nutrient for growth, although there was a greater amount of each nutrient available to the plant. This has practical significance in the application of fertilizers in the field since a portion of the fertilizer applied may be wasted and not utilized by the plant. Thus, small amounts of fertilizer applied in several applications may be more beneficial to creeping bentgrass than large amounts of fertilizer applied infrequently.

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