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Quantifying turfgrass-available N from returned clippings using anion exchange membranes

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QUANTIFYING TURFGRASS-AVAILABLE N FROM RETURNED CLIPPINGS USING ANION EXCHANGE MEMBRANES

Kelly L. Kopp* and Karl Guillard

ABSTRACT

Returning clippings can provide N to turf, but the amount of plant-available N derived from clippings is not easy to quantify. An accurate estimate of N released by clippings would be useful in guiding turf N fertilizer recommendations. The objective of this study was to determine if anion-exchange membranes (AEMs) could be used to quantify plant-available soil N when clippings are returned. A greenhouse and two field experiments were set out in randomized block designs using a factorial arrangement of 2 clipping practices [removed (CRM) and returned (CRT)] and 4 rates of N fertilization (0 to 392 kg N ha^{-1} yr^{-1}) on a cool-season lawn turf. Cumulative N uptake in the clippings was determined and correlated to AEM desorbed NO_3–N. Returning clippings resulted in greater overall N uptake and AEM desorbed NO_3–N. However, the response of N uptake to AEM desorbed NO_3–N was not the same for CRM and CRT treatments. Uptake was greater for CRT than CRM at any given AEM desorbed NO_3–N level past the minimum values. This suggests that, in addition to NO_3–N, other N forms (most likely NH_4–N) are being released from the clippings and taken up by the turf. Anion-exchange membranes alone are not adequate to quantify the plant-available N provided by returned clippings. To accurately assess the total pool of plant-available N to turf when clippings are returned with ion-exchange technology, cation- and anion-exchange resins are needed to quantify the total plant-available N pool derived from clippings.

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INTRODUCTION

The practice of returning grass clippings to managed turfgrass areas is generally beneficial to turf growth and quality and reduces the amount of green waste entering landfills (Starr and DeRoo, 1981; Heckman et al., 2000; Harivandi et al., 2001; Kopp and Guillard, 2002a; Bigelow et al., 2005). It has been suggested that N rates to cool-season lawn turf could be reduced by as much as ~33 to 50% when clippings are returned (Starr and DeRoo, 1981; Heckman et al., 2000; Kopp and Guillard, 2002a), based on the comparison of growth and quality responses from turf fertilized at varying N rates with clippings either removed or returned. Age of the turf will also influence suggested reductions in N rates when clippings are returned, based on long-term simulations with the CENTURY model (Qian et al., 2003). According to this model, when clippings are returned, N requirements can be reduced by 25% from 1 to 10 yr after turf establishment, by 33% 11 to 25 yr after establishment, by 50% 25 to 50 yr after establishment, and by 60% after 50 yr.

Returning grass clippings to turf after mowing may provide considerable amounts of N to the system. Concentrations of N in the clippings and amount of clippings produced, however, will be dependent upon specific site conditions and can vary markedly. Cumulative N loading from clippings across the growing season from cool-season turfgrasses may range from ~70 kg ha^{-1} under unfertilized conditions to ~400 kg ha^{-1} under mineral fertilization rates of 392 kg N ha^{-1} yr^{-1}, in addition to the N from previously returned clippings (Starr and DeRoo, 1981; Haley et al., 1985; Harivandi et al., 2001; Kopp and Guillard, 2002a; Engelsjord et al., 2004; Frank et al., 2006; Liu and Hull, 2006;

Kauer et al., 2007). Although not all the N in the clippings will be immediately plant-available, these N-loading amounts are approximately equal to or in excess of the yearly quantity of N recommended for moderate- to high-quality turf in temperate regions. Decomposition and mineralization of N in turfgrass clippings is relatively rapid. Laboratory soil incubations with bermudagrass (*C. dactylon* X *transvaalensis*) clippings showed that 20 to 30% of clipping C and N was mineralized by 7 d (Shi et al., 2006). Clippings of Kentucky bluegrass (*Poa pratnesis* L.) and creeping red fescue (*Festuca rubra* L.) contained within litterbags placed in the thatch layer of field plots had a 62% loss in dry matter weight after 8 weeks of incubation (Kauer et al., 2007). After 16 weeks of incubation under field conditions in the thatch layer, clippings of Kentucky bluegrass, creeping red fescue, and perennial ryegrass (*Lolium perenne* L.) within litterbags underwent mean losses of 90 and 94% of the original amounts of N and C contained in the fresh clippings, respectively (Kopp and Guillard, 2004). In a 25-week laboratory incubation study with two different soil types, the mineralization rate of the organic N in grass clippings was 26 to 66% (Rogers et al., 2001). When placed in litterbags within the middle layer of a compost layer in field plots, grass clippings released 97% of the initial N by the end of 364 d (Valenzuela-Solano and Crohn, 2006).

As turf nutrient management practices come under increased scrutiny because of environmental and economic concerns, it is more important to quantify or estimate the contributions of clippings to the pool of plant-available N in turf systems. Failure to adjust N rates when clippings are returned could lead to an increase in N leaching losses (Qian et al., 2003; Kopp and Guillard, 2005) or increased fuel and labor

requirements due to more frequent mowing needed to maintain the increased growth stimulated by additional N (Fluck and Busey, 1988; Heckman et al., 2000). A reliable method to account for mineralized soil N when clippings are returned is desirable. Although laboratory soil incubations with clippings are informative, they are time consuming and cannot mimic the dynamic *in situ* conditions encountered in the field. For example, as clippings filter down through the turf canopy into the thatch layer, they may not have immediate contact with soil flora and fauna involved with decomposition. Litterbags containing clippings placed in the thatch layer address field condition dynamics to some extent, but these are also time consuming to install and sample, and also exclude larger decomposers such as earthworms. Clippings can be collected, weighed, and analyzed for N, but this practice would not be feasible on a routine basis for most turf managers or homeowners. Additionally, available soil N transported to plant parts other than leaves or not taken up by the grass would not be measured. Traditional soil tests provide a measure of plant available nutrients. However, N is generally not measured in soil tests for turfgrass recommendations because of poor correlations with turf responses (Rieke and Ellis, 1974).

An ideal technique for determining soil NO_3–N in field situations should impose minimal soil disturbance and account for the plant-available soil N dynamics of specific sites. Anion-exchange membranes (AEMs) have been examined as a tool for continuous *in situ* measurement of the plant availability of NO_3–N in various field situations. These flat, fiber-backed membranes adsorb nutrients via exchange reactions that have the potential to mimic root activity in the soil (Abrams and Jarrell, 1992). The quantity of nutrient adsorbed on an AEM,

therefore, may be related to and influenced by the concentration of that nutrient in the soil (Robertson et al., 1999).

Desorbed AEM NO_3–N has been positively correlated to the amount of fertilizer N applied and forage yields in grassland systems (Ziadi et al., 1999; Collins and Allinson, 1999), and with plant N uptake in forage and oil crops (Qian et al., 1992; Qian and Schoenau, 1995; Ziadi et al., 1999; Qian and Schoenau, 2005). As far as we know, the first uses of AEMs in turfgrass were reported by Desjardins et al. (1998) and Simard et al. (1998). Since then, soil NO_3–N desorbed from AEMs has been related to turfgrass clipping yield, visual quality, color (Kopp and Guillard, 2002b; Mangiafico and Guillard, 2005; Mangiafico and Guillard, 2006), clipping N uptake (Mangiafico and Guillard, 2007b), and nitrate leaching (Mangiafico and Guillard, 2007a; Barry et al., 2009).

Returned clippings represent a source of recyclable N that may reduced the need for supplemental fertilization of turf areas. Having the ability to reliably and rapidly measure plant-available soil N originating from clippings would be beneficial to turf managers from environmental, economic, and agronomic perspectives. Therefore, the objective of this study was to determine the differences in plant-available NO_3–N, as measured with AEMs, when clippings are returned or removed from cool-season turf and to use this as a measure to better formulate N recommendations.

MATERIALS AND METHODS

Greenhouse Experiment

A Paxton fine sandy loam soil (coarse-loamy, mixed, active, mesic Oxyaquic Dystrudept) was collected at the

University of Connecticut's Plant Science Research and Teaching Farm (Storrs, Connecticut, USA) and placed into 7.5-L, 20.3-cm diam. pots. The soil was amended with lime and phosphorus per soil test recommendations and seeded six weeks prior to the first fertilization with a 35% common Kentucky bluegrass (*Poa pratensis* L.), 35% common creeping red fescue (*Festuca rubra* L.), 15% 'Cutter' perennial ryegrass (*Lolium perenne* L.), and 15% 'Express' perennial ryegrass mixture (percentage by weight). The pots were arranged in a 2 × 4 factorial, set out in a randomized complete block design with four replicates in a greenhouse maintained at 21/13 °C day/night. A whitewash-shading compound (Continental Products Co., Euclid, Ohio, USA) was applied to the greenhouse roof and walls each April and removed each October, resulting in a 38% reduction in natural light intensity during this period. Within blocks, pots were rotated weekly to account for any within-block variability.

Three split, equal applications of N fertilizer were made (equivalent to 0, 98, 196, and 392 kg N $ha^{-1}yr^{-1}$) and clippings were either returned (CRT) or removed (CRM) to the pots. Fertilizer was applied during weeks 5, 12, and 20 of the 29-week long (April–Nov.) experiment in the form of reagent grade ammonium nitrate. In addition to the treatment N amounts, the equivalent of 49 kg N ha^{-1} was applied at time of seeding to facilitate grass establishment. Pots were maintained at a lawn mowing height of 3.8 cm. Water was applied every day or every other day to produce adequate turf growth but to not induce leaching.

Anion-exchange membranes were used to measure plant-available NO_3–N in the soil root zone of this experiment. Membrane strips were obtained from a large sheet of vinyl copolymer AEM fabric embedded with NH_4^+ anion exchange groups (part # P5393102, type AR204SZRA, GE Water & Process Technologies, Watertown, Massachusetts, USA) cut into 2.5 × 6.35-cm segments. The specific methodology of preparing AEMs for use followed Ziadi et al. (1999). A single AEM was inserted into each of the pots one week prior to seeding to establish background desorbed NO_3-N levels. Membranes were then exchanged weekly throughout the experiment period. As the grass became established and began to require clipping, the membranes were used to measure *in situ*, plant-available soil NO_3–N. A near-vertical slit was made in the soil with a mason's trowel and AEMs were inserted, contacting the soil from 10 to 16 cm deep. Complete contact between the AEMs and the soil was made by pressing the slit closed by hand. A monofilament line was attached to each AEM to facilitate removal. As each AEM was removed from the pots, a new AEM was inserted. After removal, the AEMs were immediately transported to the laboratory for analysis. In the laboratory, the sample bottles containing the AEMs were shaken for 1 hour with 25 ml of 1M sodium chloride and the extracts were filtered through soil analysis papers (8–12 μ retention range, Schleicher and Schuell, Keene, NH). The extracts were analyzed for NO_3–N concentration on a Scientific Instruments continuous flow analyzer (WESTCO, Danbury, Connecticut, USA) using a colorimetric, Cd-reduction method and converted to units of μg per unit area of the membranes per day.

At the time of weekly membrane exchange, clippings were collected and dried in a forced-draft oven (70˚C) until a constant weight was reached, and then ground in an UDY Mill (UDY Corp., Ft. Collins, Colorado, USA) to pass through a

0.5-mm screen. While all clippings were removed from the CRM pots, clipping subsamples (10% of the total wet weight of clippings) were collected from the CRT pots and the remaining clippings were returned to and spread evenly over the pots from which they had been removed. Subsamples of clippings were analyzed using a LECO FP-2000 Carbon/Nitrogen Analyzer for the determination of total N concentration (LECO Corp., St. Joseph, Michigan, USA). The uptake of N in the clippings (mg pot^{-1}) was determined as clipping dry weight × N concentration. For CRT pots, the dry weight of the subsample was used to estimate the dry weight of the total sample for the purposes of determining total clipping dry weight.

Treatment effects on soil desorbed AEM NO_3–N and N uptake in the clippings were determined by analysis of variance (AOV) using the MIXED procedure of SAS (version 9.1.3, SAS Institute Inc., Cary, North Carolina, USA). A two-parameter logarithm model, using AEM desorbed NO_3-N as a continuous variable, was fit to N uptake response experimental unit data for both clippings returned and removed treatments using the NLIN procedure of SAS. Significance of the sum of square reduction between full and reduced models of the clipping treatments (Seber and Wild, 1989) justified the development of separate models in the greenhouse study.

Field Experiments
Two field experiments were conducted across 2-yr at the University of Connecticut's Plant Science Research and Teaching Farm (AF) and Spring Manor Farm (SM), Storrs, Connecticut, USA (Kopp and Guillard, 2002a, 2002b). The soil at one site (AF) was a Paxton fine sandy loam (coarse-loamy, mixed, active, mesic Oxyaquic Dystrudept) and the soil at the second site (SM) was a variant of a Hinckley gravelly sandy loam (sandy-skeletal, mixed, mesic Typic Udorthent). At each site, the experiments were arranged as a 2 × 4 factorial, and set out in a randomized complete block design with three replicates on a 3-yr old Kentucky bluegrass–ryegrass–fescue turf established with the same seed mixture used in the greenhouse experiment. Fertilizer and clipping treatments at the field sites were the same as in the greenhouse study. The fertilizer N formulation in the field, however, was a mixture of 94.8% soluble and 5.2% water insoluble N. The 2 × 2-m plots were mowed weekly or every other week, depending on growing conditions, at a height of 3.8 cm. Clipping samples and subsamples were collected from all plots to obtain a measure of clipping yield and N uptake following the same procedures as described in the greenhouse experiment above. Supplemental irrigation was not applied during the experiment.

Anion-exchange membranes were used to measure plant-available NO_3–N in the soil root zone of these experiments and followed the same procedures as described in the greenhouse experiment above. Two AEM strips (each 6.25-cm long × 2.5-cm wide) were inserted and replaced weekly in each plot from 23 May to 11 Nov. in the first year and from 24 May 24 to 27 Oct. in the second year. Desorbed NO_3–N from the AEMs was measured using the procedures described above for the greenhouse experiment and statistical analyses also followed the procedures described above. Significance of the sum of square reduction between full and reduced models of the clipping treatments (Seber and Wild, 1989) justified the development of separate models in the field study for all site-years, except SM Year 1.

RESULTS AND DISCUSSION

Returning clippings generally increased N uptake with a mean across N rates of 61% in the greenhouse study and 150% in the field studies. Returning clippings also increased AEM desorbed NO_3–N with a mean across N rates of 24% in the greenhouse study and 37% in the field studies. Forty percent greater uptake of N by turfgrass has been measured when clippings are returned, and labeled-N has been used to identify one-third of the N measured in harvested clippings as being from previously returned clippings (Starr and DeRoo, 1981). The amount of plant-available N provided by the clippings will vary with site-specific conditions, with the labile fraction becoming quickly available, and with the recalcitrant fraction taking longer to become available. This is consistent with laboratory and field litterbag studies reporting release characteristics of N from grass clippings (Rogers et al., 2001; Kopp and Guillard, 2004; Shi et al., 2006; Valenzuela-Solano and Crohn, 2006; Kauer et al., 2007).

We initially hypothesized that AEM desorbed NO_3–N would provide a reliable means to model N uptake by measuring the plant-available N released from the clippings since soil NH_4–N is typically low in turfgrass areas and does not fluctuate greatly (Lee et al., 2003). In fact, the response from our greenhouse and field studies did show that a higher AEM desorbed NO_3–N value corresponded with a higher N uptake value (Table 1). The percentage increases in AEM desorbed NO_3–N for CRT, however, were not as great as those observed in N uptake, and the N uptake response was not the same between the CRM and CRT treatments. A single curve response was not adequate to explain the N uptake irrespective of clipping management, and different curves were needed to model N uptake for CRM and CRT. The observed differences in response were consistent in the greenhouse (Fig. 1), across different site-years in the field (Fig. 2A, B, C, D), and with pooled data from all site-years from the field study (Fig. 2E).

AEM soil NO_3–N, $\mu g\ cm^{-2}\ d^{-1}$			
Clipping management			
Experiment	**Removed**	**Returned**	**_p_-value**
GH	3.81	4.74	0.0299
AF Y1	1.60	2.33	0.0138
AF Y2	1.60	2.80	0.0003
SM Y1	1.48	1.69	0.1995
SM Y2	2.75	3.51	0.0005

N uptake, mg pot^{-1} GH; kg ha^{-1} field			
Clipping management			
Experiment	**Removed**	**Returned**	**_p_-value**
GH	306	492	<0.0001
AF Y1	82	267	<0.0001
AF Y2	83	277	<0.0001
SM Y1	117	150	0.0098
SM Y2	103	222	<0.0001

Table 1. Clipping management effects on mean anion-exchange membrane (AEM) desorbed soil NO_3–N and N uptake in the clippings of Kentucky bluegrass-perennial ryegrass-creeping red fescue lawn turf grown under greenhouse (GH) conditions, and field conditions at two sites (AF, SM) and years (Y1, Y2) in Storrs, Connecticut, USA. Significant differences between clipping management treatments for a given experiment are indicated by the _p_-value.
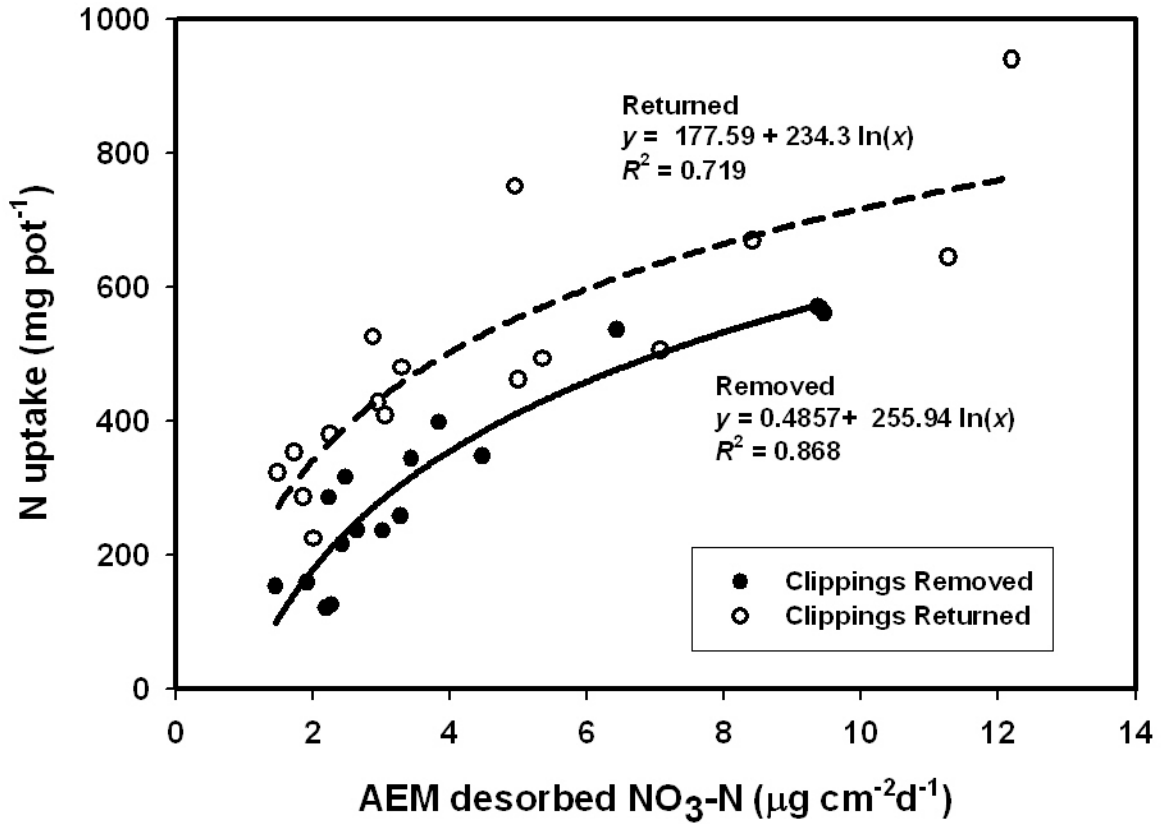
Figure 1. N uptake response of Kentucky bluegrass-perennial ryegrass-creeping red fescue lawn turf fertilized with varying rates of N in relation to anion exchange membrane (AEM) desorbed soil NO_3–N under greenhouse conditions with clippings removed or returned (Storrs, Connecticut, USA). Open circles indicate return of clippings. Closed circles indicate removal of clippings.
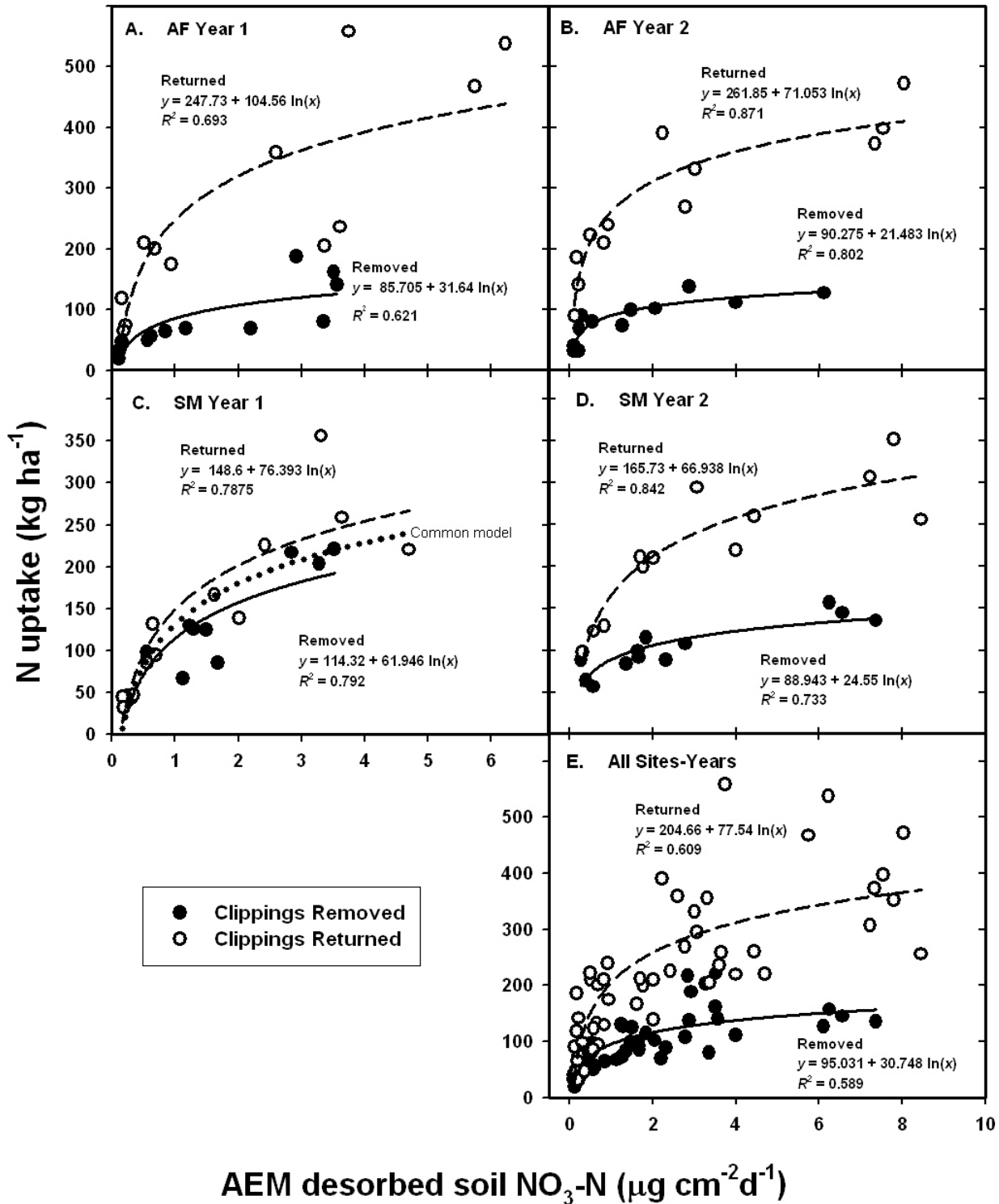
Figure 2. N uptake response of Kentucky bluegrass-perennial ryegrass-creeping red fescue lawn turf fertilized with varying rates of N in relation to anion exchange membrane (AEM) desorbed soil NO_3–N at the Agronomy Farm (AF) site (A, B), the Spring Manor Farm (SM) site (C, D), and across both sites and years (E) with clippings removed or returned (Storrs, Connecticut, USA). Open circles indicate return of clippings. Closed circles indicate removal of clippings.

In every instance, N uptake at the lower values of AEM desorbed NO_3–N were approximately the same, but quickly diverged as AEM desorbed NO_3–N increased. Consequently, predicted N uptake at a given AEM desorbed NO_3–N value, under moderate to high soil N status, was greater for CRT than for CRM. There are three possible explanations for this finding: (1) N forms other than NO_3–N (most likely NH_4–N), and not measured by AEMs, were released from the clippings and rapidly taken up by the turf before being converted into NO_3–N, (2) N released by the clippings and converted to NO_3–N was intercepted in the thatch layer before reaching the AEMs, or (3) dissolved organic N or organic matter was competing with NO_3–N for exchange sites on the AEMs.

We did not implement a soil sampling protocol for these studies that would have allowed us to measure the various soil N forms. Previous studies conducted on annual agricultural field crops suggested that AEMs were comparable (Pare et al., 1995) or superior to soil extraction of NO_3–N (Wander et al., 1995) for measurements of mineralized N in agricultural cropping systems where organic amendments or crop residues were incorporated into the soil on a regular basis. Therefore, soil sampling was deemed unnecessary for our studies. Further, soil NH_4-N concentrations under turfgrass have been shown to be relatively stable even with fertilization (Miltner et al., 2001).

During the decomposition of grass clippings, considerable amounts of NH_4–N may be released (Watson, 1986; Sullivan et al., 2004; Ao et al., 2007) and we believe that NH_4–N from returned clippings was taken up by the shallowly-rooted turfgrasses in our studies. Uptake of NH_4–N by turfgrasses is rapid, with greater uptake efficiency at lower-N status than at higher-N status (Bowman and Paul, 1988; Bowman et al., 1989a, 2006). Additionally, uptake of N in the form of NH_4–N is greater than that taken up in the form of NO_3–N (Watson, 1986; Bowman et al., 1989b). We also observed rapid N uptake response at low-N status, which leveled off as N status became adequate (Fig. 1, 2). Since most cool-season turfgrass roots are distributed near the soil surface and decrease with depth (Agnew and Carrow, 1985; Glinski et al., 1993; Murphy and Zaurov, 1994), they are well positioned to intercept NH_4–N (or NO_3–N) before movement into the deeper root zone. The uptake of NH_4–N, which cannot be measured with AEMs, may largely explain the discrepancies between the N uptake response curves of CRM and CRT in our studies.

A second potential reason for the discrepancies in N uptake response that we observed was that N released by the clippings, and potentially converted to NO_3–N, may have been intercepted in the thatch layer before reaching the AEMs. Ammonium-N applied to the thatch layer of Kentucky bluegrass may be removed and is unlikely to move past this layer (Bowman et al., 1989a). The greenhouse experiment was a newly established study and conducted before a thatch layer of any consequence developed. The differences in N uptake between CRM and CRT (Fig. 1) were not as great as was observed for most of the field data (with the exception of SM Year 1; Fig. 2C). It is possible that the returned clippings were coming into contact with soil, and that the conversion of NH_4–N derived from the clippings to NO_3–N was facilitated by this contact. In addition, the soil in the greenhouse study had been recently removed from the field. Mixing and aerating of the soil could have resulted in increased mineralization of N

and the recent establishment of turf in the pots may not have allowed for maximum rooting depth and volume to be developed. In the field, the plots had been established for 3 yr before experimental data were collected. The thatch layer was more developed and thicker than in the greenhouse turf. It is likely that more of the clippings in the field were accumulating on top of the thatch layer and were not in contact with the soil. Therefore, less NH_4–N derived from the clippings would be converted to NO_3–N and sorbed to AEMs or made available for uptake by the shallow turf roots in or near the thatch layer.

Thirdly, although we believe that uptake of NH_4–N is the most likely reason for differences in observed N uptake responses between CRM and CRT, there is also the possibility that other ions or compounds competed for exchange sites on the AEMs, reducing soil AEM desorbed NO_3–N. Organometals or dissolved organic N (DON) and organic matter (DOM) may reduce the efficacy of nutrient sorption on exchange resins (Krause and Ramsal, 1987; Langlois et al., 2003). However, it has been reported that the rate of exchange of organic ions with inorganic counterions decreases as the size or weight of the organic ion increases (Fu and Symons, 1990; Tan and Kilduff, 2007). Since most of the DON/OM molecules typical in turf soil would be of relatively large molecular weight (humic and fulvic substances >1k Daltons), it is unlikely that competition from these organics with NO_3–N for exchange sites on the AEMs resulted in marked differences in N uptake when clippings were returned or removed.

CONCLUSIONS

Anion-exchange membranes alone are not adequate for quantifying the plant-available N provided by returned clippings to managed turfgrass stands. To accurately assess the total pool of plant-available N under this management practice with ion-exchange technology, cation-exchange membranes (CEMs) are needed to quantify N in the NH_4–N form, in addition to AEMs for quantifying N in the NO_3–N form. Positioning of the CEMs would also be critical in that most of the clipping-derived NH_4–N would probably be located within or immediately below the thatch layer. Placement of both AEMs and CEMs such that the thatch and rootzone depths are included would increase accuracy and reliability of plant-available N measurements in turf. Further studies are required to test and validate these assumptions before exchange resins can be used to guide the decrease in N fertilizer rates for turf when clippings are returned.

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