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ST. AUGUSTINEGRASS RESPONSE TO NITROGEN SOURCES UNDER CONTRASTING APPLICATION RATES AND FREQUENCY

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ABSTRACT

In Florida, urban fertilizer regulations limit per-application nitrogen (N) rates to 49 kg N ha^{-1} in efforts to reduce NO_3-N ground water contamination. County and city municipalities have imposed further restrictions that prohibit N fertilization during the 4-mo rainy season in Florida, which may nullify the benefits of using slow-release N sources (SRNS) for turfgrass management. A field study compared turfgrass response of polymer-coated urea (PCU), controlled-release liquid (CRL), and Milorganite® biosolid (BS) products applied at 49, 98, and 147 kg N ha^{-1} on 60, 120, and 180 d intervals, respectively. Treatments were compared by evaluating visual turfgrass quality and clipping yields; while N release was assessed using urea as a baseline applied every 60 d at 49 kg N ha^{-1}. Turfgrass quality and yield were significantly affected by SRNS, rate, and application frequency. Nitrogen release from SRNS at current regulated N rates was insufficient to provide quality and yields comparable to urea. The most uniform SRNS response was obtained from PCU at 98 kg N ha^{-1}. At higher rates residual N release was insufficient to maintain good turf quality throughout the desired 180-d window, although all SRNS applied at 147 kg N ha^{-1} were capable of producing acceptable turf quality during restricted periods with careful application timing. The wide diversity of agronomic responses within N class between management factors exemplifies the importance of conducting further SRNS evaluations on St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze] where environmental implications are assessed before committing to regulatory rate and source limitations.

Abbreviations: BS, activated sewage sludge bio-solid; CRL, controlled release liquid; FLREC, Fort Lauderdale Research and Education Center; K, potassium; N, nitrogen; P, phosphorus; PCU, polymer coated urea; SRNS, Slow-release nitrogen sources; UF, ureaformaldehyde; UPCU, urea and polymer coated urea combinations.

Keywords: clipping yield, regulated N rates, slow-release N, St. Augustinegrass, *Stenotaphrum secundatum*, turf quality

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INTRODUCTION

Recent land use trends suggest an increasing use of St. Augustinegrass *Stenotaphrum secundatum* (Walt.) Kuntze in urban landscapes with currently an estimated 810,000 ha in Florida (Trenholm and Unruh, 2007). Urban landscapes have been implicated as a potential non-point source contributor to N species degradation of surface and ground water (Petrovic, 1990). Statewide fertilizer labeling legislation was introduced in response to mounting concerns over the impact of urban fertilization practices on Florida's water resources. The enactment limits per application nitrogen rates to 49 kg N ha^{-1}, of which, the water-soluble N portion should not exceed 34 kg N ha^{-1} (Florida Department of Agricultural and Consumer services (FDACS), No. 4640400, Rule 5E-1.003, 2007).

Legislative bodies at the county/city level have imposed further restrictions. In March 2007, the City of Sanibel introduced Ordinance No. 07-003 and Sarasota County followed later that year with Ordinance No. 2007-63; these enactments prohibit N fertilization during the traditional rainy season in South Florida from Jun 1 through Sep 30 (FDACS, Legislation and Rules, 2008). Rate regulation has been imposed unilaterally across all N sources and may negate the best features of SRNS, which are more effective when applied at infrequent higher per-application rates (Skogley and King, 1968; Hummel and Waddington, 1984; Williams et al., 1997) with reduced potential for N leaching (Snyder et al. 1981 and 1984). This legislation may rule out the option to fertilize judiciously with higher rates of SRNS and sustain good turf quality throughout rainy season 'black out' periods. Ironically, if poor turf quality results, environmental impacts may be intensified with fertilizer loading with more soluble N sources before prohibitory fertilizer periods in efforts to sustain good turf quality. There is a clear need to evaluate St. Augustinegrass quality and growth response under varying N sources, application rates, and frequencies to better understand the efficacy of N rate regulation. A companion study is currently underway to assess the environmental implications in terms of N leaching of such fertilization practices.

Nitrogen-based fertilizers for residential lawns are broadly categorized as quick or slow release depending on release duration, although several sub-classes exist within these delineations (Turner and Hummel, 1992). The benefits of slow release fertilizers, the most notable of which is reduced N leaching (Petrovic, 1990), have been well documented (Snyder et al., 1981; McCarty, 1994). While, increased uptake efficiency of applied soluble-N has been shown for St. Augustinegrass relative to other warm season grasses (Bowman et al., 2002), little is known about St. Augustinegrass responses to differing application rates and frequencies of SRNS.

Many SRNS are commercially available and stringent fertilizer restrictions exemplify the importance of evaluating each source to determine rate and frequency recommendations. Milorganite®, an activated sewage sludge has been evaluated extensively on turfgrass for over fifty years (Turner and Hummel, 1992). Sartain (1999) reported Milorganite® compared less favorably to mixed component organic fertilizers for St. Augustinegrass quality; stating N release was too gradual from the unilateral mineralization rate of the organic material. Other studies noted slow initial responses or lower visual quality compared to soluble N sources (Moberg et al., 1970; Volk and Horn, 1975; Carrow, 1997).

Liquid slow release N fertilizers could be beneficial in the lawn care industry due to the mode of application. The chemical characteristics of these formulations vary, although differential microbial degradation of urea and reacted N species provides the mechanism for extended N release. Studies suggest reduced NH_3 volatilization and N leaching are associated with urea-triazone products compared with urea and ammonium nitrate (Clapp, 1991 and 2001) Nonetheless, more evaluations on the performance of these products; particularly on St. Augustinegrass are needed.

Polymer-coated urea (PCU) is a relative new technology described by Goertz (1991). PCU releases N by osmotic diffusion through the polymeric coating, whereby coating thickness controls the release duration (Christianson, 1988). Field studies have shown PCU provides consistent release patterns within the desired window (Hummel, 1989; Peacock and DiPaola, 1992) and through the alteration of polymer chemistry and coating thickness, can offer wide range flexibility in N-release patterns. However, an initially slow response has been observed compared to urea (Carrow, 1997). Hence, soluble N sources are sometimes included in blends as *bridging* products to provide increased initial responses.

The objectives of this study were therefore (1) to determine if slow-release fertilizers applied under current regulator control can provide acceptable turf quality, (2) to evaluate St. Augustinegrass quality in response to different N sources applied at various application rates and frequency. Of particular interest was the longevity of turf response from SRNS applied before potential 'black out' periods at rates higher than currently permitted, and (3) to compare treatment effects on clipping yields under variable N management using yield comparisons with the lawn care industry standard, urea, to determine initial and long term response.

MATERIALS AND METHODS

The field study was replicated over a 12-mo period at the Fort Lauderdale Research and Education Center (FLREC) of the University of Florida from 30 Apr 2007 through 9 May 2008 using St. Augustinegrass (*Stenotaphrum secundatum* Walt. Kuntze cv. 'Floratam'). The sand grown sod was established 6-mo prior on mined medium-fine sand (very coarse 0.2%, coarse 5.4 %, medium 29.9%, fine sand 62.9%, very fine sand 1.5%, and silt and clay 0.1%) having similar textural characteristics to the Margate/Hallandale fine sand series (Siliceous, Hyperthermic Lythic Psammaquent) found in this coastal plain region. Periodic soil-testing, sampled to a depth of 10 cm, averaged across all plots revealed a pH of 7.0, 2.5% organic matter, very high P (Weak Bray P1 63 mg kg^{-1}), and high K (51 mg kg^{-1}). Due to high K mobility in sandy soil, muriate of potash at 49 kg K ha^{-1} was applied every 90-d, but no supplementary P was required (Trenholm and Unruh, 2003). Micro-nutrients were applied as Harrell's Max Minors® containing Mg 1%, S 3.5%, B 0.02%, Cu 0.25%, Fe 4%, Mn 1%, Zn 0.6% and Mo 0.0005% at 12.3 L product in 420 L water ha^{-1} every 90-d to ensure adequate tissue concentrations (Sartain, 1985).

The 2 x 4 m plots were arranged in a randomized complete block design with 3 replicates; N sources, N application rates, and frequencies (Table 1).applications were on 30 April, 30 June, 31 August, 9 November, 2007, and 7 Jan, and 7 March, 2008. Dates for 98 kg ha^{-1} applications were

Table 1. N source designation, description, application information used in the study.

Code†	Description	%N	Per app. rate (kg N ha^{-1})	App. cycles year^{-1}	Manufacturer
CRL1	12% Urea; 18% methylene urea and triazone	30	49	6	Georgia-Pacific, Inc. Decatur, GA
CRL2	12% Urea; 18% methylene urea and triazone	30	98	3	Georgia-Pacific, Inc. Decatur, GA
CRL3	12% Urea; 18% methylene urea and triazone	30	147	2	Georgia-Pacific, Inc. Decatur, GA
PCU1	Polymer-coated urea	42	49	6	Pursell Inc., Sylacauga, AL
PCU2	Polymer-coated urea	42	98	3	Pursell Inc., Sylacauga, AL
PCU3	Polymer-coated urea	42	147	2	Pursell Inc., Sylacauga, AL
BS1	Lawn grade activated sewage sludge bio-solid	6	49	6	Milorganite, Miliwaukee, WI
BS2	Lawn grade activated sewage sludge bio-solid	6	98	3	Milorganite, Miliwaukee, WI
BS3	Lawn grade activated sewage sludge bio-solid	6	147	2	Milorganite, Miliwaukee, WI
UPCU1	50:50 N combination urea:polymer-coated urea	44	49	6	Pursell Inc. & PCS Sales, Inc
UPCU2	50:50 N combination urea:polymer-coated urea	44	98	3	Pursell Inc. & PCS Sales, Inc
Urea	Granular	46	49	6	PCS Sales, Inc. Northbrook, IL

† Source code: CRL = Control release liquid; PCU = Polymer-coated urea; BS = Activated sewage sludge biosolid; UPCU = Urea in combination with polymer-coated urea.

30 April, 31 August, 2007, and 7 January, 2008, while the 147 kg ha^{-1} applications were on 30 April and 9 November, 2007. All treatments totaled 298 kg N ha^{-1} yr^{-1}, which is within best management practice guidelines for N fertilization to St. Augustinegrass in South Florida (Trenholm and Unruh, 2003). The controlled-release liquid treatment was applied in solution at 181 ml m^{-2} using a CO_2 sprayer, equipped with two flat-fan TeeJet 8010 nozzles on 50 cm spacing. Granular sources were hand sprinkled. The irrigation system configuration (i.e. 2 plots per irrigation zone) permitted all treatments to be watered into the turf immediately follow applications to reduce volatile N losses (Torello and Wehner, 1983; Waddington et al., 1993). Irrigation was schedule 3 times per week delivering approximately 0.6 cm at each event, including post-treatment.

Fertilizer responses were evaluated in terms of St. Augustinegrass quality and clipping yield. Visual quality assessment were made every two weeks on a one to nine scale in increments of 0.5; nine was dark green turf, one represented dead, brown turf, and six was deemed minimally acceptable (Carrow, 1997). Clipping samples were harvested from each of the plots, removed, and sub-sampled for shoot growth, approximately weekly during the experiment 1 and every two weeks during experiment 2 at a 75 mm height of cut. Samples were oven dried at 60°C for 48 hrs to a constant weight and reported in g m^{-2} day^{-1}. The climate in South Florida is subtropical and varies seasonally as shown by data obtained from the University of Florida's automated weather station located approximately 300 m from the experimental site (Table 4). Clipping yield and quality rating data were subjected to analysis of variance using with PROC GLM (SAS Institute, 1999) and the means were separated by Waller-Duncan Multiple range test, K ratio=100 (P<0.05).

RESULTS AND DISCUSSION

St. Augustinegrass quality and yield assessments.

St. Augustinegrass quality and yields were significantly affected by N source, N rate, and application frequency for both experimental periods (Tables 2a, 2b, 3a, 3b). Average quality ratings were not significantly different between the two experimental periods that encompassed both the wet and dry seasons in South Florida, although clipping yields were significantly reduced in the latter, reflecting periods of sub-optimal climatic conditions for warm season grass growth (Moore et al., 2004).

Comparisons of N sources applied at 49 kg ha^{-1} at 60-d intervals.

Fertilizer treatments were divided into six cycles per annum (Table 1). In the first cycle PCU and BS were slow to induce satisfactory ratings (Table 2a). Cumulative turf quality increases during cycle 2 suggest residual N release from preceding applications may be sufficient to sustain adequate turf quality (Table 2a). Compared to other sources at this N rate, CRL plots were of inferior quality (P<0.05). When averaged, clipping yields from CRL were 27 and 22% of urea in experiment 1 and 2, respectively (Table 3a, 3b). Carrow (1997) reported reduced mowing requirements and visual quality from bermudagrass treated with a similar UF reaction product compared to urea, however differences were less pronounced.

Polymer-coated urea resulted in higher numerical ratings than BS, although differences (P<0.05) were only noted 33 days after treatments (DAT) in cycle 2, 60 DAT in cycle 3, and 11, and 63 DAT, in cycle 6. (Table 2a, 2b).

Table 2a. Visual assessments during the wet season (29 April through 30 October, 2007) as influenced by N source.

Source§	Experiment 1 St. Augustinegrass Quality Rating Dates													
	04/29	05/08	05/31	06/20	06/27	07/27	08/02	08/24	09/07	09/23	10/06	10/19	10/30	Avg. ¶
	Ratings (1-9 Scale)													
60-d Cycle	-----	-----	Cycle 1	-----	-----	-----	Cycle 2	-----	-----	-----	Cycle 3	-----	-----	
DAT†	**0**	**9**	**32**	**52**	**59**	**27**	**33**	**55**	**7**	**23**	**36**	**49**	**60**	
CRL1	5.3‡	5.8ef	5.0d	5.5f	5.5f‡	6.3e	6.7de	6.3d‡	6.2e	6.2gh	5.5f	6.0de	5.3f‡	5.8h
PCU1	5.3‡	5.3f	5.0d	5.8ef	6.3cde‡	7.3abc	7.8a	7.7a‡	7.0cd	7.2def	7.5abc	7.2ab	7.0bcd‡	6.9c-f
BS1	5.2‡	6.3c-f	6.0bcd	6.0def	6.3cde‡	7.2bcd	7.2bc	7.3abc‡	6.8cde	7.2def	6.8cde	6.8bc	6.2e‡	6.8def
UPCU1	5.3‡	7.0a-d	5.8cd	6.0def	6.0ef‡	7.2bcd	7.8a	7.3abc‡	8.0ab	7.7bcd	7.5abc	6.8bc	7.2bc‡	7.1bc
Urea	5.7‡	7.8a	7.2ab	6.3c-e	6.8bcd‡	7.8a	7.5ab	7.5ab‡	8.3a	8.2ab	7.7ab	6.8bc	6.5cde‡	7.4ab
120-d Cycle	-----	-----	-----	-----	Cycle 1	-----	-----	-----	-----	-----	-----	-----	Cycle 2 --	
DAT†	**0**	**9**	**32**	**52**	**59**	**89**	**95**	**117**	**7**	**23**	**36**	**49**	**60**	
CRL2	5.3‡	7.3abc	6.5abc	6.2def	6.2def	6.3e	6.8cde	6.7cd‡	6.5de	7.0ef	6.3e	6.2de	6.2e	6.6fg
PCU2	5.3‡	5.3f	5.7cd	7.2abc	7.5ab	7.2bcd	7.7a	7.5ab‡	7.5bc	7.5cde	7.8ab	7.5a	8.2a	7.3ab
BS2	5.3‡	6.0def	6.5abc	6.7cde	7.0bc	7.0cd	6.5e	7.0a-d‡	6.7de	7.8bc	7.3bcd	7.3ab	7.0bcd	7.1bc
UPCU2	5.3‡	7.7ab	7.7a	6.8bcd	7.2ab	7.0cd	7.0cd	7.3abc‡	8.2ab	8.5a	8.2a	7.3ab	7.6ab	7.7a
180-d Cycle	-----	-----	-----	-----	-----	-----	-----	Cycle 1	-----	-----	-----	-----	-----	
DAT†	**0**	**9**	**32**	**52**	**59**	**89**	**95**	**117**	**131**	**147**	**160**	**173**	**184**	
CRL3	5.5‡	7.4abc	7.2ab	6.5cde	6.3cde	6.7de	6.8cde	6.8bcd	6.8cde	5.2i	5.3f	5.7e	5.0f‡	6.2gh
PCU3	5.3‡	5.5f	6.2bcd	7.8a	7.8a	7.7ab	7.8a	7.7a	8.0ab	6.7fg	7.3bcd	6.3cd	6.3de‡	7.0bcd
BS3	5.7‡	6.7b-e	7.7a	7.7ab	7.3ab	7.0cd	7.2bc	7.2abc	7.2cd	5.8h	6.7de	6.2de	5.3f‡	6.7ef
Significance	ns	***	***	***	***	***	***	**	***	***	***	***	***	***

ns, *, **, ***, = P>0.05, P<0.05, P<0.01, P<0.001

Ratings based on a 1-9 scale in increments of 0.5, 9 = dark green turfgrass, 1 = dead turfgrass, 6 = minimally acceptable turfgrass.

Means with the same letter within a column are not significantly different according to Waller-Duncan K-ratio = 100 t-Test.

DAT† = Days after treatments.

‡ Fertilization events followed harvest dates.

¶ Average quality rating for the experimental period.

§ Source code: CRL 1, 2, and 3 = Control release liquid applied at 49 kg N ha^{-1}, 98 kg N ha^{-1}, and 147 kg N ha^{-1}, respectively; PCU 1, 2, and 3 = Polymer-coated urea applied at 49 kg N ha^{-1}, 98 kg N ha^{-1}, and 147 kg N ha^{-1}, respectively; BS 1, 2, and 3 = Activated sewage sludge biosolid appliec at 49 kg N ha^{-1}, 98 kg N ha^{-1}, and 147 kg N ha^{-1}, respectively; UPCU 1 and 2 = Urea in equal N combination with polymer-coated urea applied at 49 kg N ha^{-1} and 98 kg N ha^{-1}, respectively.

Table 2b. Visual assessments during the dry season (7 November, 2007 through 9 May, 2008) as influenced by N source.

Source§	Experiment 2 St. Augustinegrass Quality Rating Dates												
	11/19	11/30	12/13	01/04	01/18	01/29	02/19	03/07	03/18	03/28	04/18	05/09	Avg. ¶
	Ratings (1-9 Scale)												
60-d Cycle	Cycle 4				Cycle 5				Cycle 6				
DAT†	**12**	**23**	**36**	**58**	**11**	**22**	**43**	**60**	**11**	**21**	**42**	**63**	
CRL1	5.7e	5.8fg	5.3e	5.7f‡	5.2f	5.5e	4.8de	4.5e‡	5.2d	5.7e	5.5cd	6.3cd	5.4f
PCU1	6.8bc	6.8bcd	6.7cd	7.0bcd‡	6.3d	6.3de	7.0ab	7.5bc‡	7.5a	7.5bc	7.7a	8.2a	7.1bcd
BS1	6.5c	6.7cd	6.8cd	6.8cde‡	6.3d	7.0bcd	6.5bc	7.0c‡	6.7bc	7.0cd	6.8ab	6.8bc	6.8de
UPCU1	7.2ab	7.2b	7.8b	7.0bcd‡	7.0c	7.5abc	7.2ab	8.2ab‡	7.7a	8.0ab	7.5a	7.7ab	7.5ab
Urea	7.5a	7.7a	8.2b	7.2bc‡	8.0a	8.2a	7.2ab	7.7abc‡	7.5a	8.5a	7.2ab	7.2abc	7.7a
120-d Cycle	Cycle 2				Cycle 3								
DAT†	**80**	**91**	**104**	**126**	**11**	**22**	**43**	**60**	**71**	**81**	**102**	**123**	
CRL2	5.7e	5.5g	5.2e	5.0g‡	5.7ef	5.8e	5.7cd	5.7d	5.0d	5.3e	5.8c	5.3de	5.5f
PCU2	7.3ab	7.2b	7.0c	6.8cde‡	6.2de	6.3de	7.0ab	8.3ab	7.3a	7.5bc	7.7a	7.7ab	7.2bc
BS2	6.8bc	6.8bcd	5.7e	5.7f‡	6.2de	6.8cd	7.0ab	7.5bc	6.5c	6.5d	6.3bc	6.5c	6.5e
UPCU2	6.8bc	7.0bc	6.7cd	6.3e‡	7.0c	7.8ab	7.3ab	8.3ab	7.5a	7.7bc	7.2ab	6.8bc	7.2bc
180-d Cycle	Cycle 2												
DAT†	**12**	**23**	**36**	**58**	**72**	**83**	**104**	**121**	**132**	**142**	**163**	**184**	
CRL3	5.7e	6.5de	6.3d	6.5de	5.2f	5.5e	4.3e	5.0de	4.7d	5.0e	4.7d	5.2e	5.4f
PCU3	5.8de	6.2ef	7.0c	7.5ab	7.8ab	8.0a	7.5a	8.5a	7.2ab	7.5bc	7.7ab	7.2abc	7.3abc
BS3	6.3cd	7.2b	9.0a	8.0a	7.3bc	7.3abc	6.7ab	7.5bc	6.3c	6.5d	5.8c	6.3cd	7.0cd
Significance	***	***	***	***	***	***	***	***	***	***	***	***	***

ns, *, **, ***, = P>0.05, P<0.05, P<0.01, P<0.001

Ratings based on a 1-9 scale in increments of 0.5, 9 = dark green turfgrass, 1 = dead turfgrass, 6 = minimally acceptable turfgrass.

Means with the same letter within a column are not significantly different according to Waller-Duncan K-ratio = 100 t-Test.

DAT† Days after treatments.

‡ Fertilization events followed harvest dates.

¶ Average quality rating for the experimental period.

§ Source code: CRL 1, 2, and 3 = Control release liquid applied at 49 kg N ha^{-1}, 98 kg N ha^{-1}, and 147 kg N ha^{-1}, respectively; PCU 1, 2, and 3 = Polymer-coated urea applied at 49 kg N ha^{-1}, 98 kg N ha^{-1}, and 147 kg N ha^{-1}, respectively; BS 1, 2, and 3 = Activated sewage sludge biosolid applied at 49 kg N ha^{-1}, 98 kg N ha^{-1}, and 147 kg N ha^{-1}, respectively; UPCU 1 and 2 = Urea in equal N combination with polymer-coated urea applied at 49 kg N ha^{-1} and 98 kg N ha^{-1}, respectively. All treatments totaled 294 kg N ha^{-1} year^{-1}.

However, when averaged, clipping yields relative to urea in the cycles 1 through 3 were 70% from the BS treatment and only 48% from PCU. Slower initial N release from PCU, together with higher yields following BS fertilization in cycle 1 and 2, presumably due to the soluble-N component in BS may explain higher clipping yields but lower actual turf quality (Table 2a, 3a). Clipping yields were more reflective of quality ratings in the second experiment where yields from PCU were 72% of urea compared to 44% in BS plots. Yield differences largely occurred in the final cycle when PCU performed numerically better than BS treatments in terms of quality and growth responses (Tables 2b, 3b).Increasing temperatures during this period appeared to coincide with turf quality improvements in PCU plots. Peacock and DiPaola (1992) made a similar observation, suggesting polymer coating permeability, dissolution rate, and N release increased with temperature.

Under this application regime, PCU stimulated quality ratings ≥ to urea only under higher ambient temperatures (Table 2a, 2b, 4) and thus N release from PCU may be largely temperature dependent under sufficient moisture (Christianson, 1988). In contrast, microbial growth required for BS degradation may be somewhat slower to respond as temperatures increase, thus influencing latent N release. Volk and Horn (1975) reported similar findings when turf responses to Milorganite and sulfur-coated urea were compared under increasing temperature.

Urea maintained good turf quality throughout each application cycle. However, UPCU1 provided more consistent turf quality relative to urea, which induced higher ratings immediately following applications but exhibited quality declines in the last quarter of several cycles. In addition, UPCU1 appeared to negate periods of slow N release observed with PCU under cooler temperatures, stimulating 40% greater average yield and statistically higher quality during a 10-wk period over cycles 4 and 5 (Tables 2b, 3b). Under current urban fertilizer restrictions, UPCU1 may offer a legitimate alternative to frequent urea applications when high quality St. Augustinegrass is desirable year-round.

Comparisons of N sources applied at 98 kg ha^{-1} at 120-d intervals.

The SRNS evaluated performed best under this 3 cycle per year regime, where cycles covered the wet and dry seasons with a transitional cycle that straddle both experimental periods. The 120-d application interval corresponded more closely with the duration of N release observed from PCU in previous studies (Fry et. al. 1993; Cisar et. al. 2001). Therefore, PCU delivered higher quality ratings than BS on 2 and 6 occasions in experiment 1 and 2, respectively, and was statistically greater than CRL throughout both experiments, albeit after relatively slow initial responses in cycle 1 and 3 (Tables 2a, 2b).

Comparisons of clipping yield 32 DAT in experiment 1 may elucidate initial release patterns; CRL, BS, and PCU induced yields of 93, 74, and 41%, respectively, compared to urea (Table 3a). These differences were less apparent in subsequent cycles where yields dropped considerably for CRL plots perhaps in part due to lower shoot density (data not included). In contrast, BS generated yields ≥ to urea 32 DAT in cycle 2 with PCU plots showing yields of 83% that of urea, conceivably implicating residual N carry-over or simply healthier turf prior to applications (Tables 3a). Yield comparisons to urea were much lower following cycle 3 applications,

Table 3a. Clipping yields during the wet season (29 April through 30 October, 2007) influenced by N source.

Source§	05/31	06/20	06/27	07/10	07/18	07/27	08/09	08/24	09/07	09/17	10/02	10/12	10/26	Avg. ¶
	Experiment 1. St. Augustinegrass Harvest Dates													
	Growth Rate (g m^{-2} d^{-1})													
60-d Cycle		Cycle 1				Cycle 2					Cycle 3			
DAT†	**32**	**52**	**59**	**10**	**18**	**27**	**40**	**55**	**7**	**17**	**32**	**42**	**56**	
CRL1	0.12cde	0.26e	0.04e‡	0.29e	0.83e	0.70cd	0.07f	0.08e‡	0.06d	0.09e	0.06d	0.33e	0.05f‡	0.23e
PCU1	0.08e	0.33de	0.05de‡	0.34de	0.91e	0.52d	0.26c-f	0.38b-d‡	0.32bcd	0.32b-e	0.27d	1.09bc	0.35de‡	0.40de
BS1	0.17cde	0.57de	0.08de‡	0.68cde	2.1b	0.93bcd	0.34bcd	0.50bcd‡	0.36bcd	0.46bcd	0.34cd	0.77cd	0.25def‡	0.58bc
UPCU1	0.18cde	0.40de	0.06de‡	0.75cde	1.75bcd	1.22bc	0.32bcd	0.46bcd‡	0.45ab	0.60ab	0.72b	1.24b	0.43bcd‡	0.66b
Urea	0.27bc	0.65cde	0.09cde‡	1.74ab	1.82bcd	1.34b	0.48bc	0.58bc‡	0.45ab	0.96a	0.77b	1.23b	0.36cde‡	0.83ab
120-d Cycle				Cycle 1								Cycle 2		
DAT†	**32**	**52**	**59**	**72**	**80**	**89**	**102**	**117**	**7**	**17**	**32**	**42**	**56**	
CRL2	0.25bcd	0.49de	0.07de	0.55cde	1.12de	0.51d	0.09ef	0.15de‡	0.13cd	0.24b-e	0.22d	0.60de	0.14f	0.35de
PCU2	0.11de	0.65cde	0.09cde	1.05bcd	2.00bc	1.25bc	0.56b	0.73b‡	0.43abc	0.34b-e	0.64bc	1.48b	0.63ab	0.77ab
BS2	0.20cde	0.75bcd	0.11bcd	0.60cde	1.05de	0.80bcd	0.18edf	0.21de‡	0.13cd	0.39b-d	0.78b	1.49b	0.60bc	0.56bc
UPCU2	0.35ab	1.10abc	0.16abc	1.15bc	1.56b-d	1.03bcd	0.28c-f	0.37b-d‡	0.32bcd	0.56b	1.16a	1.95a	0.86a	0.83ab
180-d Cycle							Cycle 1							
DAT†	**32**	**52**	**59**	**72**	**80**	**89**	**102**	**117**	**131**	**141**	**156**	**166**	**180**	
CRL3	0.43a	0.80bcd	0.11bcd	0.83cde	1.27cde	0.71cd	0.13def	0.16de	0.09d	0.14de	0.07d	0.31e	0.06f‡	0.39de
PCU3	0.13cde	1.14ab	0.16ab	2.27a	3.38a	1.96a	1.14a	1.23a	0.73a	0.51bc	0.34cd	0.71cde	0.15ef‡	1.07a
BS3	0.45a	1.28a	0.18a	1.07bc	1.94bc	1.18bc	0.30c-f	0.35cde	0.22bcd	0.15cde	0.11d	0.40de	0.09f‡	0.58bc
Significance	***	**	**	***	**	***	***	***	**	**	***	**	***	***

ns, *, **, ***, = P>0.05, P<0.05, P<0.01, P<0.001

Means with the same letter within a column are not significantly different according to Waller-Duncan K-ratio = 100 t-Test.

DAT† Days after treatments.

‡ Fertilization events followed harvest dates.

¶ Average growth rate for the experimental period.

§ Source code: CRL 1, 2, and 3 = Control release liquid applied at 49 kg N ha^{-1}, 98 kg N ha^{-1}, and 147 kg N ha^{-1}, respectively; PCU 1, 2, and 3 = Polymer-coated urea applie 49 kg N ha^{-1}, 98 kg N ha^{-1}, and 147 kg N ha^{-1}, respectively; BS 1, 2, and 3 = Activated sewage sludge biosolid applied at 49 kg N ha^{-1}, 98 kg N ha^{-1}, and 147 kg N ha^{-1}, respectively; UPCU 1 and 2 = Urea in equal N combination with polymer-coated urea applied at 49 kg N ha^{-1} and 98 kg N ha^{-1}, respectively. All treatments totaled 294 kg N $year^{-1}$.

Table 3b. Clipping yields during the dry season (9 November, 2007 through 9 May, 2008) influenced by N source.

Source§	Experiment 2. St. Augustinegrass Harvest Dates											
	11/09	12/02	12/13	01/06	01/14	02/09	02/22	03/07	03/26	04/23	04/29	05/09	Avg. ¶
	-----	-----	-----	-----	-----	$g\ m^{-2}\ d^{-1}$	-----	-----	-----	-----	-----	-----	
60-d Cycle	----- Cycle 4 -----				----- Cycle 5 -----				----- Cycle 6 -----				
DAT†	**0**	**25**	**36**	**60**	**7**	**33**	**46**	**60**	**19**	**47**	**53**	**63**	
CRL1	0.04f	0.03e	0.03e	0.01e‡	0.01e	0.02f	0.17abc	0.02g‡	0.03d	0.01d	0.06d	0.02d	0.04c
PCU1	0.26bcd	0.08de	0.08de	0.02de‡	0.02de	0.05def	0.11bcd	0.12bc‡	0.15bc	0.10a	0.30bcd	0.21a	0.13ab
BS1	0.16c-f	0.07e	0.06e	0.01e‡	0.02e	0.04ef	0.07bcd	0.04efg‡	0.08cd	0.06a-d	0.24cd	0.11a-d	0.08bc
UPCU1	0.30bc	0.14bcd	0.13bcd	0.03cde‡	0.04bcd	0.08cd	0.12a-d	0.10cd‡	0.19b	0.11a	0.53ab	0.19ab	0.16a
Urea	0.23cde	0.20a	0.19a	0.04a‡	0.05a	0.13b	0.12a-d	0.08c-f‡	0.24b	0.10a	0.69a	0.13a-d	0.18a
120-d Cycle	--- Cycle 2 -----				----- Cycle 3 -----								
DAT†	**70**	**93**	**104**	**128**	**7**	**33**	**46**	**60**	**79**	**107**	**113**	**123**	
CRL2	0.10f	0.05e	0.04e	0.01e‡	0.01e	0.04ef	0.05cd	0.03fg	0.03d	0.01d	0.05d	0.03d	0.04c
PCU2	0.57a	0.17ab	0.16ab	0.03ab‡	0.04ab	0.05def	0.07bcd	0.12bc	0.20b	0.08abc	0.40bc	0.14a-d	0.17a
BS2	0.40b	0.09cde	0.09cde	0.02cde‡	0.02cde	0.07cde	0.11bcd	0.09cde	0.07cd	0.02cd	0.10cd	0.05d	0.09bc
UPCU2	0.62a	0.18ab	0.17ab	0.03ab‡	0.05ab	0.13b	0.20ab	0.17b	0.23b	0.05a-d	0.32bcd	0.09bcd	0.19a
180-d Cycle	----- Cycle 2 -----												
DAT†	**0**	**25**	**36**	**60**	**68**	**94**	**105**	**119**	**138**	**166**	**172**	**182**	
CRL3	0.05f	0.06e	0.05e	0.01e	0.01e	0.02f	0.03d	0.02g	0.03d	0.01d	0.06d	0.05d	0.03c
PCU3	0.13def	0.05e	0.05e	0.01e	0.01e	0.23a	0.25a	0.24a	0.36a	0.09ab	0.56ab	0.17abc	0.18a
BS3	0.07f	0.15abc	0.14abc	0.03abc	0.04abc	0.10bc	0.07bcd	0.06d-g	0.08cd	0.02bcd	0.12cd	0.17abc	0.08bc
Significance	***	***	***	***	***	***	*	***	***	**	**	**	***

ns, *, **, ***, = $P>0.05$, $P<0.05$, $P<0.01$, $P<0.001$

Means with the same letter within a column are not significantly different according to Waller-Duncan K-ratio = 100 t-Test.

DAT† Days after treatments.

‡ Fertilization events followed harvest dates.

¶ Average growth rate for the experimental period.

§ Source code: CRL 1, 2, and 3 = Control release liquid applied at 49 kg N ha^{-1}, 98 kg N ha^{-1}, and 147 kg N ha^{-1}, respectively; PCU 1, 2, and 3 = Polymer-coated urea applied at 49 kg N ha^{-1}, 98 kg N ha^{-1}, and 147 kg N ha^{-1}, respectively; BS 1, 2, and 3 = Activated sewage sludge biosolid applied at 49 kg N ha^{-1}, 98 kg N ha^{-1}, and 147 kg N ha^{-1}, respectively; UPCU 1 and 2 = Urea in equal N combination with polymer-coated urea applied at 49 kg N ha^{-1} and 98 kg N ha^{-1}, respectively. All treatments totaled 294 kg N ha^{-1} year^{-1}.

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Table 4. Weather data for the entire experimental period (May 2007 – April 2008) for the FLREC, Florida.

Air Temperatures										Avg. Soil Temperatures (-10cm)		Total Rainfall		Avg. Solar Radiation	
Experiment 1					Experiment 2										
Month	**Max**	**Min**	**Avg.**	**Norm†**	**Month**	**Max**	**Min**	**Avg.**	**Norm†**	**Exp. 1**	**Exp. 2**	**Exp.1**	**Exp. 2**	**Exp. 1**	**Exp. 2**
	°C					°C				°C		mm		w m^{-2}	
May	33.4	15.0	25.1	25.8	Nov.	29.3	12.8	22.5	22.8	26.0	23.41	110.5	60.0	242.7	158.4
June	34.5	19.8	26.1	27.3	Dec.	29.5	10.3	22.5	20.1	27.3	23.0	345.2	14.7	222.4	146.9
July	34.1	15.3	27.3	28.1	Jan.	29.2	3.3	19.9	19.6	28.2	21.1	185.4	41.6	223.1	141.5
Aug.	35.0	22.7	28.5	27.9	Feb.	31.9	8.7	22.1	19.2	29.2	22.4	43.4	126.7	237.0	168.0
Sept.	34.9	22.1	27.4	27.2	March	32.3	10.4	23.4	22.1	28.3	22.7	277.9	125.0	193.0	192.1
Oct.	32.66	0	26.8	25.5	April	32.2	12.7	23.5	23.6	26.5	25.1	266.2	68.8	149.6	256.1
Mean	34.09	15.8	26.9	27.0	Mean	30.7	9.7	22.1	21.2	27.6	23.0	204.8	72.8	211.3	177.2

Norm † indicate averages from 2003 to 2007.

although source ranking remained unchanged, indicating that lower temperatures play a much greater role for N release in SRNS compared to urea (Tables 3b, 4).

UPCU2 outperformed SRNS in terms of quality ratings and stimulated mean ratings per cycle almost identical to that of urea. Clipping yields from UPCU2 were for the most part undistinguishable from urea ($P<0.05$), however a peak of N release between 30 and 60 DAT induced numerically higher yields and during cycle 2 statistically elevated yields. More importantly, both yield and turf quality did not differ significantly ($P>0.95$) between UPCU2 and urea in the latter stage of each 120-d cycle (Tables 3a,b), indicating a good overall performance. Numerous studies (Landschoot and Waddington, 1987; Peacock and DiPaola, 1992; Carrow, 1997) whose conclusions substantiated our findings that slow-release N in combination with soluble sources offer viable alternatives to frequent applications of urea.

Comparisons within N Sources applied at 147 kg ha^{-1} at 180-d intervals.

The SRNS evaluated were unable to provide N release through the entire 180 d window, although differences in initial and long-term response were observed. CRL imparted acceptable St. Augustinegrass quality for approximately 120 d and 35 d with acceptable turf quality apparent 9 and 23 DAT for experiment 1 and 2, respectively (Table 2a, 2b). Clipping yields reflected the experimental variability; maximum yields for CRL compared to urea were 159 percent greater in the first cycle by 32 DAT, but only 30 percent by 25 DAT in the second cycle. Minimums in both cycles were 9 percent relative to urea (Table 3a, 3b).

In previous studies involving various UF reaction products (Landschoot and Waddingtion, 1987; Carrow 1997) found sources that provided good initial responses were less effective over extended release durations. Our results are consistent with these findings over the 180-d cycle; visual quality of CRL plots declined significantly in the latter stages of each cycle (Tables 2a, 2b), which substantiates the recommended 60 to 90 d reapplication interval (Georgia-Pacific, 2007). Variations between experimental periods were apparent with reduced response longevity observed during the second cycle. Carrow (1997) noted bermudagrass growth but not response longevity differences under UF fertilization on fine textured soil due to climatic variation between experimental periods. In our study, the slow-release component (i.e. methylene urea and triazone) may not be retained long enough within the high sand soil to permit microbial action under lower soil temperatures (Table 4). Furthermore, DiPaola et. al. (1982) reported root length of St. Augustinegrass declines below 20°C, so both factors may have contributed to reduced N utilization (Petrovic, et. al., 1986).

Initial turf quality and clipping yield responses from BS were similar to CRL during the first experiment, although BS maintained initial responses with gradual yield increases from 166% at 32 DAT to a maximum of 200% at 59 DAT compared to urea. In this cycle BS exhibited statistically greater yield and turf quality relative to CRL (Table 2a, 3a). Our results are consistent with incubation studies by Lee and Peacock (2005) that demonstrated the bulk of N release occurs between 36 and 80 d following Milorganite® application.

Despite lower soil temperatures, more rapid turf quality response to BS treatments together with higher average seasonal quality ratings occurred in the second cycle. The 4% Fe content in BS may have allowed better N response during the brief cold weather snaps. Under such conditions, improved responses to N fertilization have been observed from sources containing Fe (Cisar and Snyder, 2004) and Fall applications to bermudagrass have provided improved turf responses with increasing temperature (White and Schmidt, 1990; Munshaw et.al., 2006). Periodic foliar application were made to balance micro-nutrient inputs from BS, however, the microbial release of plant-available Fe complexed with organic chelates in association with lower Fe availability under reduced soil temperatures (Carrow et al., 2001) may have biased BS treatments. Conversely, other N source response studies (Skogley and King, 1968; Volk and Horn, 1975; Landschoot and Waddington, 1987; Lee and Peacock, 2005) that compared Milorganite® did not reported attempts to balance organic micro-nutrients components or such biases.

Quality ratings illustrated more uniform, extended release patterns perhaps in part due to residual N carry-over from the first cycle. It is also possible that N release from BS (i.e., mineralization) is more tightly coupled to plant demand. In other words, N release from BS was more biologically driven while PCU was driven by the physical environment. These results suggest BS applied under this extended regime appears more suited for dry season conditions in South Florida.

Both PCU and BS provided acceptable turf quality of comparable 150-d periods during the cycle 1. Initial responses were considerable slower, 32 DAT for PCU compared to BS where quality was deemed acceptable 9 DAT, however, weighed against other SRNS, PCU stimulated superior quality ratings ($P<0.05$) for a large proportion of this cycle (Table 2a). The data also indicates that all SRNS tested would be capable of sustaining adequate turf quality for the 120-d fertilizer 'black out' period imposed by certain local legislative bodies. Both PCU and BS at this rate provided adequate turf quality for an extra 30-d period, denoting the potential to reduce application rates to provide sufficient turf quality for enforced black outs.

The delayed turf response from PCU was less apparent in the second cycle, although compared to BS plots that exhibited perfect turf quality (i.e., rating 9) 36 DAT; the more gradual release patterns from PCU provided elevated quality for longer durations. Total cumulative yields for PCU were similar to urea in both seasons. However, excessive yields concentrated into moderately short periods produced peaks of 2.5 and 3 times that of urea during cycle 1 and 2, respectively (Tables 3a, 3b). Carrow (1997) reported greater mowing requirements from a similar PCU product relative to urea and this may prove unacceptable in the lawn care industry where clipping disposal may have financial and environmental implications.

CONCLUSION

This study has shown that acceptable turf quality is possible with high frequency, low application rates of SRNS; however we found that lower frequency, higher application rates of many SRNS produce increased turf quality and yield. Thus, limiting application rates reduce optimal slow release performance with respect to these agronomic factors. For instance, at current regulated rates imposed on slow-release fertilizers in Florida, PCU provided acceptable quality St. Augustinegrass but slower initial responses were noted. The higher per-application rates, which exceeded current regulated rates, over more extended periods, resulted in better turf quality, particularly for PCU at 98 kg N ha^{-1} on a 120-d release window. Seasonal performance differences were noted, whereby, BS exhibited more enhanced responses during the cooler, dry season at 147 kg N ha^{-1} on the 180-d cycle. Even so, the SRNS evaluated were inadequate in terms of either initial or long term response relative to urea applied at 60-d intervals, although we found that all SRNS applied at 147 kg N ha^{-1} were capable of delivering acceptable turf quality for the 120-d fertilizer black out period. Our findings indicated that slow-release N in combination with soluble sources (e.g. UPCU) offered a viable alternative to frequent applications of urea. The relatively poor performance of several SRNS at high frequency, low rates compared to low frequency, high rates suggest the need for further research on the environmental implications in terms of N leaching and for more extensive evaluations of SRNS on St. Augustinegrass.

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