Late Fall and Winter Nitrogen Fertilization of Turfgrass in Two Pacific Northwest Climates

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Abstract. Late fall N fertilization of cool-season turfgrass in northern climates is a common practice. Previous research has been focused in climates where freezing temperatures prevail. Research in more moderate northern climates where turf may not go through winter dormancy is scarce. Four fertilizer N sources and an untreated control were applied in four different months (November, December, January, or February) to perennial ryegrass (*Lolium perenne* L.) in Puyallup, Wash., and to kentucky bluegrass (*Poa pratensis* L.) in Pullman, Wash., to compare their effects in moderate (Puyallup) and freezing (Pullman) winter climates. In Pullman, only November applications of ammonium sulfate (AmS) or polymer coated sulfur coated urea (PCSCU) enhanced winter turfgrass quality. In Puyallup, November or December application of AmS, PCSCU, or polymer coated urea (PCU) resulted in enhanced winter quality. Polymer coated urea yielded a delayed initial response and a longer residual effect in the spring. Isobutylidenediurea (IBDU) did not improve winter turf quality in either Pullman or Puyallup. Although there was no quality response following January fertilizer application, there was suppression of red thread [*Laetisaria fuciformis* (McAlpine) Burds.] symptoms in Puyallup, indicating N uptake. Late fall fertilizer N in eastern Washington should be confined to November, using soluble or more quickly available slow-release nitrogen fertilizers. The application window can be extended to December in western Washington, and more slowly available coated ureas can be effectively used.

Late fall N fertilization of cool season turfgrass in northern climates has become widely practiced over the last 15 to 20 years. Recommendations vary state-by-state, but generally include application of N at rates from 4.9 to 7.4 g·m⁻² from November to mid-December (Rieke and Lyman, 2002; Stahnke et al., 2000; Street and White, n.d.). Recommended fertilizer types include soluble quick-release sources such as urea, ammonium nitrate, and ammonium sulfate, and slow release sources such as coated urea products.

Although visible growth of turf is slow during this time, the plant still takes up and utilizes N. Miltner et al. (1996) recovered 36% of ¹⁵N-labeled urea in verdure 18 days after November application to kentucky bluegrass (*Poa pratensis*). Miltner et al. (2001) found that leaf tissue N content was higher in November than any other month in both fertilized and unfertilized perennial ryegrass (*Lolium perenne*). Wilkinson and Duff (1972) measured higher leaf chlorophyll content in November-fertilized kentucky bluegrass compared to unfertilized turf. Powell et al. (1967) measured higher photosynthetic rates in January in creeping bentgrass (*Agrostis stolonifera* L.) fertilized monthly from October

through January compared to October only.

Many researchers have reported improved color in winter and/or early spring in response to late fall N fertilization (Koski and Street, 1985; Ledebauer and Skogley, 1973; Powell et al., 1967; Wehner et al., 1988; Wehner and Haley, 1993). Enhanced root development has also been reported (Koski and Street, 1985; Moore et al., 1996). These effects occur without rapid top growth through the winter (Ledebauer and Skogley, 1973; Powell et al., 1967; Wehner et al., 1988). The biggest potential drawback of late fall N application reported in the literature was decreased freezing tolerance of kentucky bluegrass measured in the laboratory, but the authors reported no winter injury in the field (Wilkinson and Duff, 1972). There is also concern that applying fertilizer at this time could lead to nitrate leaching, but Miltner et al. (1996) observed that less than 0.1% of November-applied urea-N leached through sandy loam soil over two years. Even so, most recommendations include the use of a slow-release N source as an added safety measure.

Pullman, Wash., is in the eastern part of the state where freezing winter temperatures, frozen soil, and snow are typical in the winter. It is in USDA Plant Hardiness Zone 6a (mean annual minimum temperature between -20.6 and -23.3 °C) (Jordan, 2003). The predominant turf species is kentucky bluegrass. The winter weather in Pullman is similar to that where most of the late

fall N research has been conducted previously. Puyallup is located west of the Cascade Mountains, where winter temperatures are milder than at more inland sites of similar latitude, including Pullman. The USDA Plant Hardiness Zone is 8a (mean annual minimum temperature between -9.5 and -12.2 °C) (Jordan, 2003). The growing season for turf in this region can be as long as 11 to 12 months. Based on information from golf course superintendents, fertilizer may be applied in any month, including January and February. Nitrogen uptake may be limited during these months due to reduced root uptake. This, in combination with precipitation patterns that result in saturated soils, may increase the potential for nutrient leaching and/or runoff. There were two objectives of this research project: to compare plant response to late fall N fertilization in the milder winter climate (USDA Zone 8a) of western Washington to that in the colder winter climate (USDA Zone 6a) of eastern Washington; and to assess the effectiveness of January and February N application in western Washington.

Materials and Methods

Experiments of similar design were conducted at two locations in Washington over the winters of 1998-99 (Year 1) and 1999-2000 (Year 2). The first site was the Farm 5 Turfgrass Research Facility at the Washington State University (WSU) Puyallup Research and Extension Center, located about 55 km southeast of Seattle, Wash. (USDA Zone 8a). The soil was a Puyallup fine sandy loam (coarse loamy over sandy or sandy-skeletal, mixed, mesic, Vitrandic Haploxerolls). Soil pH was 5.8 and soil P and K contents were 35 and 234 mg·kg⁻¹, respectively. The perennial ryegrass (49% 'SR 4200', 25% 'SR 4010', and 25% 'SR 4100' w/w) turf was established by seed in April 1998. The second site was in Pullman, Wash., about 480 km east of the Puyallup location (USDA Zone 6a). The soil was a Palouse silt loam (fine silty, mixed, mesic Pachic Ultic Haploxerolls). Soil pH was 6.2 and soil P and K contents were 94 and 471 mg·kg⁻¹, respectively. The turf was 'Eclipse' kentucky bluegrass established from seed in May 1992. Perennial ryegrass and kentucky bluegrass are the predominant turfgrass species in each of these respective regions. The two locations allow for a comparison of plant response to N fertilization in the milder winters of Puyallup to the colder winters that occur in Pullman and through most of the northern U.S. Weather stations near both sites recorded environmental conditions during the experimental periods. In Pullman, there was no weather station on site. Data was collected from a National Oceanic and Atmospheric Administration (NOAA) weather station located at the Pullman Wash./Moscow, Idaho, airport located approximately 3 km from the research site. In Puyallup, the on-site weather station malfunctioned, and so data was collected from a WSU Public Agricultural Weather System (PAWS) weather station located about 8 km from the experimental site. Daily air temperature and precipitation data were collected at both sites. Neither site had soil temperature sensors.

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Four nitrogenous fertilizer sources (N Source) were used, plus a control that received no late fall or winter fertilizer application. The sources were ammonium sulfate (AmS) 21N-0P-0K-24S, polymer coated sulfur coated urea (PCSCU) (Best TriKote 43N-0P-0K-12S, J.R. Simplot Company, Lathrop, Calif.), polymer coated urea (PCU) (Best PolyOn 44N-0P-0K, J.R. Simplot Company, Lathrop, Calif.), and isobutylidenediurea (IBDU) (31N-0P-0K, Vigoro Industries, Fairview Heights, Ill.). Polymer coated sulfur coated urea is a urea prill first coated in sulfur, then a plastic-like polymer. In PCU, the sulfur coating is omitted, and the polymer coating is thicker than in PCSCU, resulting in slower N release. Relative N release rates of the four N Sources could be ranked as AmS > PCSCU > PCU ≥ IBDU (Carrow, 1997; Wehner et al., 1988). Previous research has indicated that IBDU may not be an effective source for late fall N fertilization (Wehner et al., 1988), but it was included here because it is widely used by professionals in western Washington.

There were four Month treatments: November, December, January, or February. Each treated plot received a fertilizer application in one and only one of these four months. N Source and Month treatments were combined factorially. The January treatments were not applied in Pullman in Year 2 due to month long snow cover on the plot area. Specific application dates in for each site appear in Table 1. All fertilizer treatments were applied to supply N at the rate of 7.4 g·m⁻² using shaker bottles to plots measuring 1.2 × 1.5 m in Puyallup and 1.5 × 1.5 m in Pullman. The experimental design was a split plot with Month as the main plot and N Source as the subplot. Plots were arranged as a randomized block with four replications at each location. Irrigation was not applied following treatment application. In Puyallup, rainfall occurs regularly during these months. In Pullman, the irrigation system was drained for the winter. Natural precipitation was relied upon to move fertilizer into the soil. This was typical of management practices used in the industry.

In Pullman, plots were mowed weekly at a height of 5 cm from April through October with a mulching rotary mower. Additional N was applied to all plots as AmS at the N rate of 4.9 g·m⁻² per application in May and September of 1998 and May, July, and August of 1999. Annual N rates for all treated plots in Pullman were 17.2 and 22.1 g·m⁻² in Years 1 and Year 2, respectively. In Puyallup, plots were mowed to a height of 5 cm with a mulching rotary mower. Mowing frequency was about every 2 weeks in December and January, and every 5 to 7 d the remainder of the year. Aside from experimental treatments, additional fertilizer was applied to all plots in May (22N-2.2P-4.2K, N rate of 7.4 g·m⁻², 50% of N as PCSCU) and September (AmS, N rate of 4.9 g·m⁻²) of both 1998 and 1999. The total annual N rate for all treated plots was 19.7 g·m⁻². In both locations, irrigation was applied as needed to maintain healthy turf. No pesticides were applied at either location throughout the term of the experiments.

Visual quality ratings were recorded at monthly intervals from December through May (Year 1) and December through April (Year 2) in Pullman. All ratings were conducted by the same person. Quality included a combination of color, plant density, and uniformity of stand. A scale of 1 to 9 was used (1 = dead turf, 9 = ideal turf, 5 = acceptable). Plots that had not yet been treated were not rated. For example, only November treatment plots were rated in December since they were the only ones that had been fertilized. Clipping samples were collected on 10 May 1999 and 12 May 2000 to measure extended growth response to the fertilization treatments. Plots were first mowed with a rotary mower to a height of 5 cm. The

height of cut of the mower was then reduced to 3.8 cm and a sample was collected from a single strip measuring 55 cm × 150 cm through the center of each plot.

In Puyallup, quality and color ratings (1 = brown, 9 = dark green) were recorded from December through June in both years. Ratings for visual symptoms of red thread [*Laetisaria fuciformis* (McAlpine) Burds.] were taken on 7 Mar. 2000 (1 = no disease, 9 = dead turf) during a period of active disease. All ratings in Puyallup were conducted by the same person (although the raters in Pullman and Puyallup were different). Clipping samples were collected on 18 May 1999 and 9 May 2000. A single strip, measuring 55 × 150 cm, was mowed to a height of 5 cm through the center of each plot, after allowing five days of regrowth from prior mowing.

Analysis of variance was conducted using the General Linear Model procedure of SAS v8.01 (SAS Institute, 2000). Because different species of grass existed at the two sites and this introduced a variable in addition to geographic location, the two sites were analyzed separately. Means separation was performed by Fisher's protected least significant difference ($P = 0.05$).

Results and Discussion

In Puyallup (USDA Zone 8a), daily average air temperatures during the months in which fertilizer treatments were applied (November, December, January, and February) were 3.3 to 5.6 °C higher than in Pullman (USDA Zone 6a) during Year 1, and 1.4 to 5.1 °C higher in Puyallup than Pullman during Year 2 (Table 2). The

Table 1. Fertilizer treatment application dates for comparison of late fall and winter nitrogen applications to turfgrass in Puyallup and Pullman, Wash., in Year 1 (1998–99) and Year 2 (1999–2000).

Treatment month	Year 1		Year 2	
	Puyallup	Pullman	Puyallup	Pullman
November	6 Nov. 1998	11 Nov. 1998	9 Nov. 1999	24 Nov. 1999
December	4 Dec. 1998	16 Dec. 1998	13 Dec. 1999	17 Dec. 1999
January	4 Jan. 1999	11 Jan. 1999	6 Jan. 2000	None ^a
February	3 Feb. 1999	20 Feb. 1999	7 Feb. 2000	18 Feb. 2000

^aNo application was made due to snow cover throughout the month.

Table 2. Means of daily maximum (max), minimum (min), and average (avg) air temperatures for each month for Puyallup (USDA Zone 8a) and Pullman (USDA Zone 6a) Wash., and temperature differentials (Puyallup–Pullman) for Year 1 (1998–99) and Year 2 (1999–2000).

Month	Mean monthly temps (°C)								
	Puyallup			Pullman			Difference (Puyallup – Pullman)		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Year 1									
November	11.8	4.6	8.1	7.2	1.7	4.4	4.6	2.9	3.6
December	7.5	0.8	4.1	1.6	–4.4	–1.4	5.9	5.3	5.6
January	6.6	1.9	4.2	3.6	–1.8	0.9	3.0	3.7	3.3
February	10.0	2.3	6.0	4.7	–1.5	1.6	5.3	3.8	4.4
March	11.6	2.1	6.6	9.0	–0.2	4.4	2.6	2.3	2.1
April	15.4	2.1	8.7	12.6	0.4	6.5	2.8	1.7	2.2
May	16.5	5.4	11.0	15.6	3.1	9.3	0.9	2.4	1.7
June	19.6	10.1	14.6	20.3	7.2	13.8	–0.7	2.9	0.8
Year 2									
November	12.7	4.8	8.3	10.9	2.9	6.9	1.7	1.9	1.4
December	8.4	3.0	5.6	2.6	–1.6	0.5	5.8	4.6	5.1
January	8.2	0.4	3.9	2.1	–3.2	–0.6	6.1	3.6	4.4
February	11.0	1.4	5.7	5.6	–0.8	2.4	5.4	2.2	3.2
March	11.9	2.2	6.9	8.6	–0.4	4.1	3.3	2.6	2.9
April	16.1	4.7	10.3	15.4	2.9	9.2	0.7	1.8	1.2
May	17.4	7.7	12.4	17.0	5.2	11.1	0.4	2.6	1.3
June	21.7	9.9	15.8	21.9	6.8	14.4	–0.2	3.1	1.4

Table 3. Effect of four nitrogen sources applied in either November, December, January, or February on turfgrass quality in Pullman, WA (USDA Zone 6a) in Year 1 (1998-99).

Month applied	N Source	Turfgrass quality (1-9) ²					
		December	January	February	March	April	May
November	Control ³	5.0 c ^x	4.8 b	4.0 b	4.0 b	5.0 c	4.5 c
	AmS	6.8 a	6.0 a	5.0 a	5.0 a	7.0 a	6.8 a
	PCSCU	6.5 a	5.8 a	5.0 a	5.0 a	6.0 a	6.3 a
	PCU	5.5 bc	5.0 b	5.0 a	5.0 a	6.8 b	6.5 ab
	IBDU	5.8 b	5.0 b	4.3 b	4.3 b	5.5 bc	5.8 b
December	Control	--- ^w	4.3	4.0	4.0	5.3 b	4.8 c
	AmS	---	4.3	4.3	4.3	5.8 ab	5.8 b
	PCSCU	---	4.8	4.5	4.5	6.3 a	6.3 ab
	PCU	---	4.8	4.5	4.3	6.5 a	6.8 a
	IBDU	---	4.5	4.3	4.3	5.3 b	6.0 ab
January	Control	---	---	4.0	4.0	5.0 d	4.3 c
	AmS	---	---	4.5	4.5	7.0 a	4.8 a
	PCSCU	---	---	4.3	4.3	7.0 a	6.8 a
	PCU	---	---	4.0	4.0	6.0 b	6.8 a
	IBDU	---	---	4.0	4.0	5.5 c	5.5 b
February	Control	---	---	---	4.0	5.0 c	4.0 c
	AmS	---	---	---	4.0	7.0 a	6.5 a
	PCSCU	---	---	---	4.0	6.3 b	7.0 a
	PCU	---	---	---	4.0	6.0 b	7.0 a
	IBDU	---	---	---	4.0	5.3 b	5.0 b

²Turfgrass quality ratings: 1 = dead, 9 = ideal.

³Control = unfertilized control, AmS = ammonium sulfate, PCSCU = polymer coated sulfur coated urea, PCU = polymer coated urea, IBDU = isobutylidnediurea.

^xValues within a column within each application month followed by the same letter are not significantly different (LSD, $P = 0.05$).

^wData was not collected for a particular Month of Application treatment until after that treatment was applied.

average minimum temperatures during these months were 2.9 to 5.3 °C higher in Puyallup than Pullman during Year 1 and 1.9 to 4.6 °C higher during Year 2. The only times that temperatures were higher in Pullman than Puyallup were in June and in later summer months (data not shown) that were not within the time frame of interest for this experiment.

Pullman (eastern Washington—USDA Zone 6a). Significant N source × year interactions existed for most of the monthly quality ratings and clipping yield in Pullman, so data were subsequently analyzed by Year to examine the effects of month and N source treatments. Significant month × N source interactions occurred for turfgrass quality ratings in Year 1. November was the only month in which fertilizer application resulted in improved turfgrass quality through the winter (Table 3). When applied in November, AmS and PCSCU were the most effective in maintaining quality through January. Quality of November-treated PCU plots was no better than the control in December and January, but November-applied PCU, AmS, and PCSCU all resulted in significantly better quality in February through May. The delayed response from PCU was not surprising given the expected slower N availability compared to AmS and PCSCU. IBDU resulted in better quality than the control only in December and May following application in November.

Following December, January, or February application, none of the fertilizers resulted in improved turf quality compared to the control until April (Table 3). All fertilizers improved April and May quality, but PCSCU, PCU, and, to a lesser extent, AmS, were more effective than IBDU. Although N application during these three months did improve quality in the spring, the data clearly indicate no effect in enhancing winter quality.

During Year 2 there was no significant

Table 4. Effect of four nitrogen sources on turfgrass quality in Pullman, Wash. (USDA Zone 6a) in Year 2 (1999–2000), averaged for the 3 months of application (November, December, February).

N Source	Turfgrass quality (1-9) ²				
	December	January	February	March	April
Control ³	4.0 b ^x	3.0 b	3.0 b	3.0 c	4.5 e
AmS	5.0 a	4.0 a	3.9 a	4.3 a	7.3 a
PCSCU	5.0 a	4.0 a	4.0 a	4.3 a	6.7 b
PCU	4.0 b	3.0 b	3.0 b	3.8 b	6.4 c
IBDU	4.0 b	3.0 b	3.0 b	3.1 c	5.3 d

²Turfgrass quality ratings: 1 = dead, 9 = ideal.

³Control = unfertilized control, AmS = ammonium sulfate, PCSCU = polymer coated sulfur coated urea, PCU = polymer coated urea, IBDU = isobutylidnediurea.

^xValues within a column followed by the same letter are not significantly different (LSD, $P = 0.05$).

month × N source interaction for turfgrass quality. The significant main effect of N Source is presented. The data support the results from Year 1. AmS and PCSCU showed the greatest and most consistent effects on turfgrass quality compared to the control (Table 4). PCU significantly improved quality in March and April only, and IBDU in April only. Clipping yield data for Year 1 showed enhanced growth in plots fertilized with AmS, PCSCU, and PCU compared to IBDU and the control (Table 5). This is further evidence of the effectiveness of these first three sources and the relative ineffectiveness of IBDU.

Puyallup (western Washington—USDA Zone 8a). Month × N source interactions occurred for four of seven quality ratings and clipping yield. Data from both years were combined and the month × N source interactions were examined. November and December application dates were both effective in enhancing winter turfgrass quality (Table 6). Following November application, turf fertilized with AmS and PCSCU responded quickly and had the highest turf quality in December, and maintained good quality into April. The response to PCU was delayed, as in Pullman. From January through June, quality ratings for November-applied PCU plots were

Table 5. Effect of four nitrogen sources on turfgrass clipping yield in Year 1 (1998–1999) and Year 2 (1999–2000) in Pullman, Wash. (USDA Zone 6a).

N source	Clipping yield (g/plot)	
	Sampling date	
	10 May 1999	12 May 2000
Control ²	42.3 b ^y	61.2
AmS	56.2 a	62.4
PCSCU	58.6 a	62.3
PCU	57.7 a	60.1
IBDU	45.2 b	59.3

²Control = unfertilized control, AmS = ammonium sulfate, PCSCU = polymer coated sulfur coated urea, PCU = polymer coated urea, IBDU = isobutylidnediurea.

^yValues within a column followed by the same letter are not significantly different (LSD, $P = 0.05$).

in the highest statistical category. Ratings for PCU were particularly high in April and May. Quality of November fertilized IBDU plots was inferior to that of AmS and PCSCU in December, and lower than PCSCU in February. In January and again in March through June, quality from IBDU was statistically equal to the highest quality ratings, although it was numerically lower in most months. All fertilizers applied in November

Table 6. Effect of four nitrogen sources applied in either November, December, January, or February on turfgrass quality in Puyallup, Wash. (USDA Zone 8a) averaged over Year 1 (1998–1999) and Year 2 (1999–2000).

Month applied	N Source	Turfgrass quality (1–9) ^c						
		December	January	February	March	April	May	June
November	Control ^y	5.0 d ^x	4.5 b	4.4 c	3.8 b	4.8 b	5.1 c	5.1 b
	AmS	6.4 a	5.5 a	5.6 ab	5.4 a	6.4 a	5.9 b	6.4 a
	PCSCU	6.3 ab	5.5 a	6.1 a	5.6 a	6.6 a	5.8 b	6.0 a
	PCU	5.9 bc	5.6 a	5.8 ab	5.6 a	6.9 a	6.8 a	6.1 a
	IBDU	5.8 c	5.4 a	5.5 b	5.1 a	6.5 a	6.3 ab	6.0 a
December	Control	--- ^w	5.0 abc	4.4 c	4.0 c	4.9 b	5.1 b	5.1
	AmS	---	5.3 ab	6.0 a	5.6 a	6.8 a	5.8 ab	5.8
	PCSCU	---	5.4 a	5.6 a	5.4 ab	6.4 a	5.5 b	5.4
	PCU	---	4.8 c	4.9 bc	5.1 ab	6.6 a	6.4 a	5.4
	IBDU	---	4.9 bc	5.0 b	4.9 b	6.5 a	6.4 a	5.4
January	Check	---	---	4.5	4.1 c	5.5	5.1 b	5.4
	AmS	---	---	5.1	5.6 a	6.5	6.0 a	5.4
	PCSCU	---	---	5.1	5.0 ab	6.4	6.1 a	5.4
	PCU	---	---	4.5	4.3 bc	6.1	5.9 a	5.5
	IBDU	---	---	4.6	4.4 bc	6.1	6.4 a	5.8
February	Control	---	---	---	3.6 c	4.8 c	4.8 d	5.4
	AmS	---	---	---	4.9 a	6.6 a	5.4 cd	5.0
	PCSCU	---	---	---	4.4 b	6.4 a	5.6 bc	5.3
	PCU	---	---	---	4.1 b	6.3 ab	6.3 ab	5.4
	IBDU	---	---	---	4.0 bc	5.6 b	6.6 a	5.6

^aTurfgrass quality ratings: 1 = dead, 9 = ideal.

^yControl = unfertilized control, AmS = ammonium sulfate, PCSCU = polymer coated sulfur coated urea, PCU = polymer coated urea, IBDU = isobutylidenediurea.

^xValues within a column within each application month followed by the same letter are not significantly different (LSD, $P = 0.05$).

^wData was not collected for a particular month of application treatment until after that treatment was applied.

Table 7. Effect of four nitrogen sources applied in either November, December, January, or February on clipping yield, averaged for 2 years (collected 18 May 1999 and 9 May 2000), and visual symptoms of red thread (*Corticium fuciforme*) recorded on 7 Mar. 2000 in Puyallup, Wash. (USDA Zone 8a).

Month applied	N source	Clipping yield (g/plot)	Red thread (1–9) ^c
November	Control ^y	12.7	3.0 a ^x
	AmS	12.0	1.8 bc
	PCSCU	13.6	1.0 d
	PCU	11.6	2.0 b
	IBDU	14.5	1.3 cd
December	Control	11.2 c	3.3 a
	AmS	15.0 b	1.0 c
	PCSCU	14.7 b	1.5 b
	PCU	18.7 a	1.3 b
	IBDU	14.6 b	1.8 b
January	Control	11.2	3.0 b
	AmS	13.1	1.0 a
	PCSCU	14.8	1.5 a
	PCU	12.5	2.5 b
	IBDU	16.8	3.0 b
February	Control	10.8 c	3.5
	AmS	13.5 b	3.3
	PCSCU	15.0 ab	3.0
	PCU	16.3 a	3.0
	IBDU	14.7 ab	2.5

^aRed thread ratings: 1 = no visual symptoms, 9 = severe symptoms.

^yControl = unfertilized control, AmS = ammonium sulfate, PCSCU = polymer coated sulfur coated urea, PCU = polymer coated urea, IBDU = isobutylidenediurea.

^xValues within a column followed by the same letter are not significantly different (LSD, $P = 0.05$).

resulted in higher quality than the unfertilized control in all rating months. As in Pullman, AmS and PCSCU were the most effective, while PCU was slightly slower to release but provided a better late spring response.

Delaying fertilizer application until De-

cember was still effective in maintaining winter quality, although somewhat less than application in November (Table 6). AmS and PCSCU resulted in higher January quality than PCU and IBDU. In April and May, PCU and IBDU-fertilized plots had the highest quality, similar to the November application.

January N fertilization was not as effective as earlier months. Turfgrass quality in February was not significantly better in fertilized plots than the control (Table 6). In March, quality of AmS and PCSCU plots was better than the for the control. All January fertilized plots had numerically higher, but not statistically higher quality than the control in April. May quality of all fertilized plots was statistically higher. These inconsistent results indicate that N was not utilized as effectively following January application. Following February fertilizer application, all plots had significantly higher quality in March than the unfertilized control (Table 6). AmS, PCSCU, and PCU resulted in the highest quality in April, while PCU and IBDU resulted in the best May quality. Overall, the inconsistent response to January N application in February, in combination with better spring quality following February treatment, makes February a better choice.

There were no significant differences in clipping yield measured in May to applications of fertilizer in November (Table 7). December application of PCU resulted in the higher clipping yields than the control and other N sources, which might be predicted based on expected release rates of these products. There was no significant response in clipping yield to January N fertilization, another indication that this date is less effective than others. All February-fertilized plots had higher clipping yield than the control, with PCU being the highest and AmS the lowest, again coinciding with the expected N release and longevity patterns.

Red thread often occurs on perennial ryegrass in western Washington in late winter to early spring when N availability is low due to cool soil temperatures and the length of time since the last fertilizer application. Application of any of the four N sources in either November, December, or January reduced the visible symptoms of red thread in March 2000 (Table 7). Note that in this rating scale, a lower value means less disease than a higher value. Goss and Gould (1971) reported decreased occurrence of red thread in Puyallup on red fescue (*Festuca rubra* L.) and colonial bentgrass (*A. capillaris* L.) in response to increasing N application rates. In their study, disease response was related to higher N availability associated with higher application rates. In our experiment, PCSCU and IBDU reduced symptoms the most following November fertilizer application. PCU and AmS were intermediate. When applied in December, AmS had the greatest impact, probably due to rapid N availability to the plant, while PCSCU, PCU, and IBDU were intermediate. This supports the turfgrass quality data: grass plants responded to N applied in November or December. When applied in January, the more readily available AmS and PCSCU significantly reduced red thread symptoms compared to the control, while PCU and IBDU had no effect. Suppression of red thread symptoms indicates that N uptake was occurring in January, although this was not apparent from quality ratings. Fertilizer application in February did not significantly impact red thread symptoms. Ratings were taken 29 days after fertilizer application, possibly too short a time span for the N to have made an impact in the plant.

These experiments indicate that late fall N fertilization in Pullman should take place no later than November. Because of colder temperatures and decreased plant activity, December application was too late to have an

effect on winter quality, an indicator that plant N uptake was probably limited. Johnston et al. (2001) observed increased potential for nitrate leaching from turf during winter months. If soluble N is present in soil due to limited plant uptake, this could result in leaching of nitrate. This recommendation is similar to those where cool season grasses are grown in the midwestern and northeastern areas of the U.S. (Rieke and Lyman, 2002; Street and White, n.d.). Nitrogen sources that are more readily available, which included AmS and PCSCU in this study, were the most effective in Pullman. Nitrogen from the more slowly soluble PCU and IBDU apparently was not available quickly enough to be utilized by the plant prior to the onset of colder temperatures. Wehner et al. (1988) previously reported that IBDU was ineffective for late fall N fertilization in Illinois.

Warmer temperatures in Puyallup (USDA Zone 8a) coincided with an extended N fertilization window compared to Pullman (USDA Zone 6a). Allen et al. (1971) found increased N release from sulfur coated urea with increasing temperature, but similar published information on the more modern N sources used in this study is lacking. The difference in grass species may have also had an impact, although Bowman et al. (1989) saw little difference in N uptake between kentucky bluegrass and perennial ryegrass immediately following fertilizer application in August. November and December were both effective fertilizer application times to enhance winter turfgrass quality in Puyallup. Ammonium sulfate and PCSCU resulted in a positive quality response in December that lasted into the spring. Although the response to PCU was not quite as rapid, there was a more extended response into May. Isobutylidenediurea was less effective through the winter months than the other three sources. Although January N fertilization was not effective in enhancing turfgrass quality in Puyallup, moderation of red thread symptoms indicated that N uptake was occurring. February N fertilization was effective in enhancing turf quality beginning in March.

Both AmS and PCSCU contained sulfur (S) (24% S and 12% S, respectively), while the other N sources did not. Brauen et al. (1975) and Goss (1974) saw positive color responses to increasing S fertilizer rates when high N rates were applied (N rates of 58 to 98 g·m⁻²·year⁻¹). However, at annual N rates of 29 g·m⁻² no response to S was observed. They concluded that S had no impact when N rates were low. Annual N rates for our studies ranged from 17 to 22 g·m⁻², considerably lower than their low

N rate. It seems unlikely that S had a major impact on our results.

Late fall N fertilization in western Washington (USDA Plant Hardiness Zone 8a) can be effectively extended into December, whereas N application should take place by November on the eastern side of the state (USDA Plant Hardiness Zone 6a). The results we observed were probably due to temperature differences between the sites, although specific data on N release rates of these different carriers as affected by temperature is not evident in the literature. Ammonium sulfate and PCSCU were effective in both locations, while PCU was also effective in Puyallup, providing slightly less winter response but an extended response in the spring. Although the soluble AmS was effective in promoting turf quality, it is generally not recommended to apply soluble N sources at rates this high (7.4 g·m⁻²) due to the perceived potential for loss via runoff or leaching, especially during times of limited plant growth. Although it might be expected that NH₄⁺-N would be held on soil exchange sites and therefore protected from leaching, Miltner et al. (2001) measured increased soil nitrate in October and November, indicating active nitrification during these cooler months. Carrow (1997) observed that there was a wide range of plant response to different fertilizer products with a given class. The products used in this study would fall into different classes as described by Carrow. Readily soluble sources such as ammonium sulfate, ammonium nitrate, and urea should produce similar results based on N availability. The effects seen from PCSCU, PCU, and IBDU in these experiments should not be extrapolated to all products within these classes. Release rates and plant response can vary depending on particle size and coating properties.

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