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Late Fall Nitrogen Application and Turf Cover for Zoysiagrass (*Zoysia japonica*) Spring Green-up

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ABSTRACT. The use of zoysiagrass (*Zoysia japonica* Steud.) in the transition zone is limited because of a lack of cold hardiness although zoysiagrass has many advantages compared to other warm-season and cool-season grasses. Late-fall N fertilization is often applied for darker green color of turfgrass in early spring and more extensive root growth without rapid top growth. The objective of the study was to evaluate the effects of late fall N application and turf cover for zoysiagrass spring green-up. Clear polyvinyl chloride (PVC) film was used for turf cover. The amount of N applied were 5 and 10 g N m^{-2} for the low and high N rate treatments, respectively. Covered zoysiagrass had greater turfgrass color and quality in early spring than non-covered zoysiagrass. The high N rate had 0.6 to 2.3 greater turfgrass quality than the low N rate on 7 of 9 rating dates. Slow-release N as late fall fertilization is more effective for turfgrass color and quality than fast-release N in spring. Turf cover could reduce the period of yellow zoysiagrass, and the earlier time of spring green-up could be advanced by increasing turfgrass quality and growth of zoysiagrass.

Key words: Late fall N application, Spring green-up, Turf cover, Zoysiagrass

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Introduction

Zoysiagrass (*Zoysia japonica* Steud.) is one of warm-season (C4) turfgrasses native to East Asia and most widely used in Korea (Christians, 2011; Engelke and Anderson, 2003). The popularity of zoysiagrass has been increased for athletic fields, golf courses, home lawns, and commercial landscapes because of its minimal nutritional and mowing requirements relative to other turfgrass species (Christians and Engelke, 1994). In addition to low requirements of nutrition and mowing, it needs less pesticides and forms a dense, uniform turf through the production and spread of rhizomes and stolons compared with cool-season (C3) turfgrass species such as Kentucky bluegrass (*Poa pratensis* L.) and creeping bentgrass (*Agrostis stolonifera* L.) (Fry et al., 2008; Turgeon, 2008). Zoysiagrass also has the ability to tolerate low light intensity (Qian and Engelke, 1999), high salinity (Lee, 1999; Qian et al., 2000), and drought conditions (White et al., 2001). Although zoysiagrass has many advantages compared to other warm-season and cool-season grasses, its extensive use in the transition zone is limited because of a lack of cold hardiness (Dunn and Diesburg, 2004). Zoysiagrass lose green pigment when soil temperatures reach below 10°C in the late autumn, and get into dormancy until soil temperatures are above 16°C in the spring (Beard, 1973; Ries et al., 2006). Freezing injury induce dehydration stress to zoysiagrass that causes membrane deterioration and eventually results in cell necrosis (Uemura and Steponkus, 1998). Of zoysiagrass species, differences of freezing tolerances between Z. *japonica* and Z. *matrella* have been reported for winter injury in field trials. Patton and Reicher (2007) reported that Z. *japonica* genotypes had 10 and 19% less winter injury than Z. *matrella* for 2005 and 2006, respectively. *Z. japonica* cultivar'Meyer' is well known for use of transition zone because of its turf quality and cold hardiness. Rogers et al. (1977) evaluated the freezing tolerance of zoysiagrass 'Meyer' and reported that 50% zoysiagrass survived between −7 and −13°C when sampled in December.

The turfgrass crown is important to recover turfgrass from low temperature stress in winter because shoots and roots can be recovered from the crown (Fry and Huang, 2004). Turf covers (TC) are often used to protect the crowns from direct low temperatures and desiccation during the winter. Roberts (1986) evaluated various TC on creeping bentgrass (*Agrostis stolonifera*) and found that polyester, polypropylene, and pine needle covers have reduced winter desiccation, and polyester blankets have enhanced spring green-up of creeping bentgrass. Tapp et al. (1988) used straw, polypropylene or polyester covers as sources of TC on bermudagrass and found TCs enhanced turfgrass quality and spring green-up for bermudagrass compared without TCs. Lee (2013) investigated the effects of various turf covers on Kentucky bluegrass and found that any type of turf covers on Kentucky bluegrass resulted in an increase of average and minimum temperature compared to the uncovered plot and among turf covers, clear PVC film without holes produced the longest root length and the highest turfgrass quality. Although data from the previous researches have been reported for the positive effects of TCs on turfgrass, it is still not clear for both cool- and warm-season grasses and negative effects may exist.

Late-fall N fertilization is often applied for darker green color of turfgrass in early spring and more extensive root growth without rapid top growth. Koski and Street (1985) investigated Kentucky bluegrass with late fall N application. They reported that late fall N application on Kentucky bluegrass produced more extensive root growth and darker spring color due to decreased an early spring N application. Turfgrass color and root growth enhanced by late fall N application were reported by many previous researchers (Ledeboer and Skogley, 1973; Moore et al., 1996; Wehner et al., 1988; Wehner and Haley, 1993). Misunderstanding of late fall fertilization have been prevalent over the last 15 to 20 years because it is believed that late fall fertilization leaded to decrease freezing tolerance. Wilkinson and Duff (1972) investigated freezing tolerance of Kentucky bluegrass treated by fall fertilization and found no winter injury. In addition to freezing tolerance, there was a disquiet about nitrogen (N) leaching. However, research data have been reported that N leaching by late fall N fertilization is insignificant. Miltner et al. (1996) reported that less than 0.1% of fall urea-N application leached through Kentucky bluegrass on sandy loam soil over two years. For the reasons, late fall N fertilization on turfgrass has become widely used to enhance spring green-up for cool-season grasses.

Most turf managers and lawn care industries want to longer period of green zoysiagrass and minimize dormancy. Based on research data, both turf cover and late fall N application for turfgrass are beneficial to spring green-up for cool-season grasses. However, data are lacking to clarify the effectiveness on zoysiagrass with late fall N application. Presumably, interaction between turf cover and late fall N application also may influence the spring green-up of zoysiagrass. The objective of the study was to evaluate late fall N application and turf cover for zoysiagrass spring green-up.

Materials and Methods

Research was initiated at the Dankook Turfgrass Research Center on the campus of Dankook University in Cheonan, Chungnam, Korea. Zoysiagrass (*Zoysia japonica* Steud.) 'junggi' was used for the study. Each plot size for the study was 0.8 by 1.2 m. The treatment list and application timing are listed in Table 1. The N applications were 5 and 10 g N m^{-2} for the low and high N rate treatments, respectively. Urea (46-0-0) as a fast-release N and methylene urea (15-5-17, Long-fair™ Dongbu Hannong) as a slow-release N was used as N sources. Clear poly-vinyl chloride (PVC) film was used for turf cover. The first application was made in December 7, 2013. After the N and turf cover applications were made, no irrigation and mowing were made until the study end. Turf color ratings are a measure of overall plot color (NTEP, 2011). The research plots of Kentucky bluegrass were covered by treatments of turf cover until the study ends to investigate the point of negative effects of turf cover. Turfgrass color was measured by an index of damage caused by disease or insect pests, nutrient deficiency or environmental stress. Turfgrass color was visually rated on a scale of 1 to 9 (1 = straw brown, 6 = acceptable, and 9 = dark green) every two weeks. Turfgrass quality was measured by an index of turf density, leaf texture, disease resistance, mowing qualities, and stress tolerance including several stresses during winter (Beard, 1973; Turgeon, 2008). Turfgrass quality was visually rated on a scale of 1 to 9 (1 = poor, 6 = acceptable, and 9 = best) every two weeks. Soil temperature was measured at the depth of 10 cm bi-weekly using the digital thermometer, (tpi-315C, TPI CE, Korea). Data of air temperature were referred by weather-i for the area of Chonan, Chungnam, Korea. Leaf and root length were measured to evaluate turfgrass growth. The experimental design was a randomized complete-block design with three replications. Analysis of variance (ANOVA) was performed on transformed data using

Table 1. Treatment list and nitrogen application plan.

Turf cover (TC)	N source[y]	N rates[z] (g m^{-2})
TC	Urea	5
TC	Urea	10
TC	Methylene urea	5
TC	Methylene urea	10
No TC	Urea	5
No TC	Urea	10
No TC	Methylene urea	5
No TC	Methylene urea	10

[y]Urea (46-0-0) as a fast-release N and methylene urea (15-5-17) as a slow-release N were used for the study.
[z]The treatment was applied at December 7, 2013.

Statistical Analysis Systems design (SAS Institute Inc., 2001). Treatment differences were analyzed by the Proc Mixed procedure. When appropriate, mean separations were performed by Fischer's protected least significant difference (LSD) at a 0.05 probability level. All statistical analyses were analyzed by SAS.

Results and Discussion

There was no consistent three-way and two-way interactions among treatments for turfgrass color and quality (Table 2). There were significant turf cover main effects for turfgrass color throughout the study with the exception of sampling dates in May 1, 2014. Covered turf had greater turfgrass color than no covered turf from April 10 to May 22 (Table 3). Non-covered turf had greater turfgrass color than covered turf from May 28 when maximum air temperature reached 30.2°C (Table 6). Lee (2013) reported similar results with turf cover study. He found non-covered turf had greater

Table 2. Analysis of variance for turfgrass color and quality.

Source	Apr. 10	Apr. 18	Apr. 26	May 1	May 12	May 16	May 22	May 28	June 17
	Turf color								
Turf cover (TC)	**	**	**	NS[z]	**	**	**	**	**
Nitrogen source (NS)	NS	NS	NS	NS	NS	*	**	*	NS
Nitrogen rate (NR)	NS	NS	**	**	**	NS	**	**	**
NS × TC	NS	NS	*	NS	NS	NS	*	NS	NS
TC × NR	NS	NS	**	NS	NS	NS	**	NS	NS
NS × NR	NS	NS	NS	NS	NS	*	NS	NS	NS
NS × TC × NR	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Turf quality								
Turf cover (TC)	**	**	**	**	**	**	**	NS	NS
Nitrogen source (NS)	NS	NS	*	NS	*	*	NS	NS	NS
Nitrogen rate (NR)	NS	**	**	**	**	NS	**	**	**
NS × TC	*	NS	**	**	NS	NS	**	NS	NS
TC × NR	NS	**	*	NS	NS	NS	**	NS	NS
NS × NR	*	NS	NS	NS	NS	NS	NS	NS	NS
NS × TC × NR	NS	NS	NS	NS	NS	NS	NS	NS	NS

*, **indicates significance at $P=0.05$ and $P=0.01$, respectively.
[z]NS indicates not significant at $P=0.05$.

Table 3. Mean turfgrass color and quality for turf cover main effect.

Turf cover[w]	Apr. 10	Apr. 18	Apr. 26	May 1	May 12	May 16	May 22	May 28	Jun. 17
	Turfgrass color								
Cover	6.6[x] a[y]	5.3 a	5.3 a	4.9	6.3 a	6.2 a	6.0 a	4.2 b	3.3 b
No Cover	1.0 b	2.0 b	3.1 b	4.4	4.2 b	4.1 b	4.4 b	5.2 a	4.6 a
	Turfgrass quality								
Cover	5.2[z] a	4.8 a	5.1 a	4.9 a	6.3 a	5.5 a	5.8 a	4.5	3.7
No Cover	1.1 b	2.0 b	3.1 b	3.9 b	4.3 b	3.7 b	4.2 b	4.0	4.0

[w]Turf cover was applied at December 7, 2013 immediately after the N treatment.
[x]Mean turfgrass color was measured by visual evaluation using 1 to 9 scale (1=straw green, 6=acceptable, and 9=dark green).
[x]Means in a column with the same upper case letters or no letters are not significantly different according to Fisher's LSD ($P=0.05$).
[z]Mean turfgrass quality was measured by visual evaluation using 1 to 9 scale (1=worst, 6=acceptable, and 9=best).

Table 4. Mean turfgrass color and quality for nitrogen source main effect.

N source[w]	Apr. 10	Apr. 18	Apr. 26	May 1	May 12	May 16	May 22	May 28	Jun. 17
	------ Turfgrass color ------								
Fast-release N	3.8[x]	3.6	4.0	4.5	5.1	4.8 b[y]	4.8 b	4.3 b	3.6
Slow-release N	3.8	3.7	4.3	4.8	5.4	5.4 a	5.6 a	5.1 a	4.3
	------ Turfgrass quality ------								
Fast-release N	3.3[z]	3.4	3.8 b	4.3	5.0 b	4.2 b	4.8	3.9	3.6
Slow-release N	3.0	3.3	4.3 a	4.5	5.6 a	5.0 a	5.1	4.6	4.1

[w]Methylene urea and urea are used as slow- and fast-release nitrogen source, respectively.
[x]Mean turfgrass color was measured by visual evaluation using 1 to 9 scale (1=straw green, 6=acceptable, and 9=dark green).
[y]Means in a column with the same upper case letters or no letters are not significantly different according to Fisher's LSD (P=0.05).
[z]Mean turfgrass quality was measured by visual evaluation using 1 to 9 scale (1=worst, 6=acceptable, and 9=best).

Table 5. Mean turfgrass color and quality for nitrogen rate main effect.

N rates[w]	Apr. 10	Apr. 18	Apr. 26	May 1	May 12	May 16	May 22	May 28	Jun. 17
	------ Turfgrass color ------								
Low	3.8[x]	3.4	3.1 b[y]	3.9 b	4.9 b	5.0	4.4 b	3.8 b	2.9 b
High	3.8	3.8	3.7 a	5.4 a	5.6 a	5.3	6.0 a	5.6 a	4.9 a
	------ Turfgrass quality ------								
Low	3.2[z]	3.0 b	3.8 b	3.7 b	4.8 b	4.6	4.2 b	3.4 b	2.7 b
High	3.1	3.8 a	4.4 a	5.2 a	5.8 a	4.6	5.8 a	5.1 a	5.0 a

[w]Low and high N rates are 5 and 10 g N m^{-2}, respectively.
[x]Mean turfgrass color was measured by visual evaluation using 1 to 9 scale (1=straw green, 6=acceptable, and 9=dark green).
[y]Means in a column with the same upper case letters or no letters are not significantly different according to Fisher's LSD (P=0.05).
[z]Mean turfgrass quality was measured by visual evaluation using 1 to 9 scale (1=worst, 6=acceptable, and 9=best).

turfgrass color than covered turf of Kentucky bluegrass when maximum air temperature reached 24.0°C. It is optimal temperature for shoot growth of cool-season grasses. In warm-season grasses, optimal temperature ranges are 27 to 35°C for shoots and 24 to 29°C for roots (Beard, 1973). The air temperature of 30.2°C measured in the study is the range of optimal temperature for zoysiagrass, but the temperature under cover could be higher than air temperature. Lee (2013) also reported that the temperature difference between air and under cover was 3.1 to 8.7°C with various types of turf covers. Therefore, the temperature under the cover could be 38.9°C which is higher than optimal temperature for shoot growth of warm-season grasses. Non-covered turf had turfgrass color lower than acceptable turfgrass color of six throughout the study. Covered turf had greater turfgrass color than acceptable turfgrass color of six on April 10 and from May 12 to May 22. However, covered turf had low turfgrass color on May 22 and June 17 due to leaf chlorosis resulted from high temperature under the cover. There were significant turf cover main effects for turfgrass quality on 7 of 9 rating dates. Covered turf had greater turfgrass quality than non-covered from April 10 to May 22. As discussed for turfgrass color, no differences between turf cover treatments were found after May 22 because of high air temperature of 30.2°C. All treatments of turf cover had lower turfgrass quality than acceptable rating of six throughout the study except covered turf on May 12 because all treatments plot were not fertilized in 2014. Without the fertilization, covered turf had greater turfgrass color than non-covered turf until maximum air temperature reach 30.2°C.

Significant differences between N sources were found for turfgrass color and quality (Table 4). Slow-release N had greater turfgrass color than fast-release N from May 16 to May 28. When the air temperature reached the optimal range for warm-season grasses, slow N had 0.6 to 0.8 greater turfgrass color than fast-release N. The rapid process of urea release is well known. Broadbent et al. (1958) found that a fertilizer application of 91 kg N was completely hydrolyzed to ammonium within two days in three soils which are Salinas clay, Yolo loam, and Sacramento clay. Therefore, fast release N may not be appropriate for the late fall N fertilization. Wehner et al. (1988) found that urea required additional spring N application for Kentucky bluegrass growth. They also found sulfur coated urea as slow-release N had greater color ratings than urea in spring. The same trends were apparent in the result of the study. For turfgrass quality, slow-release N had 0.5 to 0.8 greater turfgrass quality than fast-release N on 3 of 9 rating dates. With similar trends with turfgrass color, slow-release N as late fall fertilization would be more effective for turfgrass quality in spring.

There was significant N rate main effects for turfgrass color and quality. The high N rate had greater turfgrass color than the low N rate from April 26 to June 17 (Table 5). The low N rate did not reach acceptable rating of six throughout the study. The high N rate had acceptable rating of six on 1 of 9 rating dates. Although the high N rate had greater turfgrass color than the low N rate, additional N fertilization is needed for optimal turfgrass color in addition to late fall N application. The high N rate had 0.6 to 2.3 greater turfgrass quality than the low N rate on 7 of 9 rating dates. Regardless change of air temperature, the high N rate as a late fall application was more effective than the low N rate. Without additional N fertilization, both the low and high N rate for late fall N application had less than acceptable quality throughout the study in 2014.

Significant turf cover main effects were found for soil temperature (Table 6). Covered turf had 1.7 to 3.7 higher soil temperature than non-covered turf on 4 of 9 rating dates. Optimal temperature ranges for root zone is 24 to 29°C for warm-season grasses (Beard, 1973). Based on the result of the study, soil temperature reached optimal range earlier in spring when turfgrass is covered with turf cover during the winter period.

Root and leaf length was affected by turf cover main effects.

Table 6. Mean soil temperature and daily air temperature for turf cover main effect.

Turf cover	Apr. 10	Apr. 18	Apr. 26	May 1	May 12	May 16	May 22	May 28	Jun. 17
	----- Soil temperature (°C) -----								
Cover	17.7[x] a[y]	22.8 a	23.7 a	20.7	19.3	26.1 a	24.8	24.7	26.4
No Cover	16.0 b	20.0 b	20.3 b	20.7	19.6	23.4 b	24.7	24.5	26.2
	----- Daily air temperature (°C) -----								
Min. Temp.	8.5[z]	10.4	9.0	9.1	14.4	10.0	11.7	18.3	19.4
Avg. Temp.	12.8	15.6	17.7	15.6	17.7	18.5	20.5	24.1	23.9
Max. Temp.	19.9	22.7	25.4	22.8	22.5	26.8	29.5	30.2	28.6

[x]Mean turfgrass color was measured by visual evaluation using 1 to 9 scale (1=straw green, 6=acceptable, and 9=dark green).
[y]Means in a column with the same upper case letters or no letters are not significantly different according to Fisher's LSD (P=0.05).
[z]Daily air temperature is not statistical data but reference data by weather-i.

Table 7. Mean root and leaf length for turf cover main effect.

Turf cover	Apr. 26	May 1	May 12	May 16	May 22	May 28	Jun. 17
	----- Root length (cm) -----						
Cover	13.1	8.8	9.7	16.0	8.8 a[y]	NA[z]	NA
No Cover	11.3	8.8	8.3	15.8	7.3 b	NA	NA
	----- Leaf length (cm) -----						
Cover	NA	NA	13.7 a	7.0 a	13.8 a	12.3 a	13.4 a
No Cover	NA	NA	8.7 b	2.5 b	9.0 b	8.6 b	9.9 b

[y]Means in a column with the same upper case letters or no letters are not significantly different according to Fisher's LSD (P=0.05).
[z]NA means not available.

Covered turf had longer root length than non-covered zoysiagrass on May 22 when maximum air temperature reached 29.5°C (Table 7). There was no difference between turf cover treatments for root length until May 16. When turf cover with clear poly-vinyl chloride (PVC) film used for Kentucky bluegrass, no differences were found between covered and non-covered turf for root length (Lee, 2013). However, covered zoysiagrass had longer root length with greater turfgrass color and quality than non-covered zoysiagrass when maximum air temperature is 29.5°C. Covered turf had longer leaf length than non-covered turf from May 12 to June 17. Differences between covered and non-covered turf for root length were found after May 16 when maximum temperature reached the optimum range for root growth of warm-season grasses. In contrast, the maximum air temperature was out of optimum range for cool-season grasses before root length of Kentucky bluegrass was measured (Lee, 2013). Compare to root length, leaf length are influenced by turf cover main effects from May 12 to June 17. Covered turf had 3.5 to 4.8 cm longer leaf length than non-covered turf throughout the study. Despite high temperature covered turf had longer leaf length than non-covered on May 28 and June 17 while non-covered turf had greater turfgrass color than covered turf and no difference was found for turfgrass quality on same rating dates. For turfgrass color, chlorosis of turfgrass leaf which is a yellowing of leaf tissue due to a lack of chlorophyll occurred by high temperature but longer leaf length was produced by covered turf. No main effects of N sources and N rates were found for root length (data not shown).

Overall, turf cover was effective for spring green-up based on the study. Covered zoysiagrass had greater turfgrass color and quality in early spring than non-covered zoysiagrass. Turf cover was applied to all treatments of Kentucky bluegrass until the study ends because there was a need to investigate the point of negative effects of turf cover as temperature increase. When maximum air temperature reached 30.2°C, chlorosis of zoysiagrass leaf occurs. It lead lower turfgrass color. High N rate of late fall application was more effective for spring green-up of zoysiagrass. Covered zoysiagrass had longer root and leaf length than non-covered zoysiagrass. Because there was no additional N application in the spring, turfgrass color and quality were less than acceptable ratings. If N fertilization is applied in the spring and constant mowing is managed, turfgrass color and quality will be improved in the spring. Short period of green zoysiagrass is the limitation to be used especially in the transition zone. Based on the study, the application of the 10 g N m^{-2} in late fall and turf cover could reduce the period of yellow zoysiagrass, and the time of spring green-up could be advanced by increasing turfgrass quality and growth of zoysiagrass.

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