



Hybrid bermudagrass response to fall-applied trinexapac-ethyl and cool-season turfgrass overseeding

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ABSTRACT: Hybrid bermudagrass (*Cynodon dactylon* × *C. transvaalensis*) is a perennial warm-season (C₄) turfgrass that enters winter dormancy, resulting in loss of green color and reduced visual quality. Maintaining acceptable turf performance during this period remains a major management challenge under Mediterranean climatic conditions. This study evaluated the effectiveness of overseeding hybrid bermudagrass with selected cool-season (C₃) turfgrass species and cultivars, in combination with trinexapac-ethyl (TE) application, to sustain turf quality, photosynthetic activity, and surface greenness during winter dormancy and the subsequent spring transition. Field experiments were conducted from October 2023 to May 2024 at Akdeniz University using five cool-season cultivars belonging to *Lolium perenne* L., *Poa pratensis* L. and *Festuca arundinacea* Schreb. under TE-treated and non-treated conditions. Turfgrass quality, normalized difference vegetation index (NDVI), relative chlorophyll content and percentage of green turf cover were evaluated throughout the winter and spring periods. Results indicated that all overseeded plots exhibited significantly higher turf quality, NDVI, relative chlorophyll content and green cover compared with non-overseeded control plots. Significant differences were observed among species and cultivars, with *L. perenne* ‘Peri’ consistently demonstrating superior performance across all measured parameters. While fall-applied TE had limited effects during winter, it enhanced the spring transition of hybrid bermudagrass. These findings demonstrate that species and cultivar selection play a critical role in overseeding success and that TE application can be strategically used to improve spring transition dynamics.

Keywords: Hybrid bermudagrass, *Lolium perenne* L., overseeding, plant growth regulator

Serin iklim çimleri ile üst ekim ve sonbahar trinexapac-ethyl uygulamalarının hibrit bermudagrass üzerine etkisi

ÖZET: Hibrit bermuda çimi (*Cynodon dactylon* × *C. transvaalensis*), kış döneminde dormansiye giren çok yıllık, sıcak iklim (C₄) çim türü olup bu süreçte yeşil rengini kaybetmekte ve görsel kalitesi azalmaktadır. Bu dönemde kabul edilebilir çim performansının sürdürülmesi, Akdeniz iklim koşulları altında önemli bir yönetim sorunu olmaya devam etmektedir. Bu çalışmada, hibrit bermuda çiminin seçilmiş serin iklim (C₃) çim tür ve çeşitleri ile üst ekimi (overseeding) ile trinexapac-ethyl (TE) uygulamasının birlikte kullanımının, kış dormansisi süresince ve bunu izleyen ilkbahar geçiş döneminde çim kalitesi, fotosentetik aktivite ve yeşil rengin korunması üzerindeki etkinliği değerlendirilmiştir. Arazi denemeleri, Ekim 2023–Mayıs 2024 tarihleri arasında Akdeniz Üniversitesi’nde, *Lolium perenne* L., *Poa pratensis* L. ve *Festuca arundinacea* Schreb. türlerine ait beş serin iklim çeşidi kullanılarak, TE uygulanan ve uygulanmayan koşullar altında yürütülmüştür. Kış ve ilkbahar dönemleri boyunca çim kalitesi, normalize edilmiş fark bitki örtüsü indeksi (NDVI), relatif klorofil içeriği ve yeşil çim örtü oranı değerlendirilmiştir. Elde edilen sonuçlar, üst ekim yapılan tüm parsellerin, üst ekim yapılmayan kontrol parsellerine kıyasla önemli derecede daha yüksek çim kalitesi, NDVI, relatif klorofil içeriği ve yeşil örtü oranı gösterdiğini ortaya koymuştur. Türler ve çeşitler arasında önemli farklılıklar belirlenmiş olup, *L. perenne* ‘Peri’ çeşidi ölçülen tüm parametrelerde sürekli olarak üstün performans göstermiştir. Sonbaharda uygulanan TE’nin kış dönemi boyunca etkileri sınırlı kalırken, hibrit bermuda çiminin ilkbahar geçiş sürecini iyileştirdiği belirlenmiştir. Bu bulgular, üst ekim başarısında tür ve çeşit seçiminin kritik bir rol oynadığını ve TE uygulamasının ilkbahar geçiş dinamiklerinin iyileştirilmesinde stratejik olarak kullanılabileceğini göstermektedir.

Anahtar kelimeler: Hibrit bermuda çimi, *Lolium perenne* L., üst ekim, bitki büyüme düzenleyicisi

INTRODUCTION

Hybrid bermudagrass (*Cynodon dactylon* × *C. transvaalensis*) is one of the most widely used warm-season turfgrass species in warm and transitional climate zones worldwide, owing to its superior turf quality and high tolerance to heat and drought stress (Beard, 1973). Its rapid establishment through aggressive stolons and rhizomes, combined with excellent traffic tolerance and strong regenerative capacity, makes hybrid bermudagrass a preferred species for high-performance turf areas such as football fields and golf courses (Severmutlu et al., 2012b; Sancar et al., 2023). However, like other warm-season turfgrasses, this species enters dormancy during the fall–winter period when soil temperatures decline below 10 °C, resulting in chlorosis and a decline in both aesthetic appearance and functional quality (Beard, 1973).

To maintain acceptable turf quality during winter dormancy, overseeding warm-season turfgrasses with cool-season species has long been adopted as an effective management practice (Deaton and Williams, 2010; Özkan and Kır, 2023). Successful overseeding requires the selection of cool-season species and cultivars that provide high turf quality throughout winter while allowing controlled removal during spring without excessive competition with bermudagrass. This is particularly important because substantial differences exist among

species and cultivars in terms of winter performance, competitive ability, and spring green-up dynamics (Christians et al., 2017). Moreover, the aggressive growth habit of hybrid bermudagrass prior to overseeding can hinder the establishment of cool-season grasses, necessitating the use of cultural practices such as reduced mowing height, verticutting, and appropriate fertilization to temporarily suppress bermudagrass competitiveness (Severmutlu et al., 2012a, 2012b).

Beyond cultural practices, the regulation of bermudagrass growth using plant growth regulators (PGRs) has been identified as a key factor influencing overseeding success. Among these, trinexapac-ethyl (TE), which inhibits gibberellic acid biosynthesis and thereby suppresses shoot elongation, has been reported as an effective growth-regulating compound in turfgrass systems (Halman, 1990; Heckman et al., 2005; Severmutlu et al., 2012a, 2012b). TE reduces cell elongation, increases mesophyll cell density and chlorophyll concentration, and results in a shorter, denser, and higher-quality turf canopy (Heckman et al., 2005). Depending on application timing and rate, TE can suppress turfgrass growth by up to 80% for 4–5 weeks (Severmutlu et al., 2012b), thereby reducing bermudagrass competitiveness and facilitating the establishment of cool-season grasses during overseeding (Deaton and Williams, 2010).

Cool-season turfgrass species such as *Lolium perenne* L., *Poa pratensis* L., and *Festuca arundinacea* Schreb. are commonly used in overseeding programs due to their rapid germination, winter color retention, surface coverage potential, and stress tolerance (Serensits et al., 2011; Rossini et al., 2019; Özkan and Kır, 2023). *L. perenne* is particularly valued for its rapid germination and establishment, whereas *P. pratensis* contributes to sod strength and surface stability through its rhizomatous growth habit. *F. arundinacea* with its broad ecological adaptability, is also considered suitable for winter turf systems (Beard, 2002). Nevertheless, the competitive interactions between these cool-season species and bermudagrass vary considerably depending on cultivar characteristics and regional climatic conditions, making species and cultivar selection a critical component of successful overseeding management (Serensits et al., 2011; Özkan & Kır, 2023).

Although the effects of TE on overseeded bermudagrass systems have been examined in previous studies, reported outcomes are highly dependent on regional climate, management practices, and species–cultivar interactions. For example, Aldahir et al. (2015) demonstrated that TE application improved winter turf quality and surface uniformity in overseeded bermudagrass; however, the magnitude of these responses varied across climatic regions and management regimes. Studies evaluating the combined effects of TE application and cool-season species selection under Mediterranean and warm-temperate climatic conditions remain limited, particularly in Türkiye. Therefore, a region-specific and integrated assessment is needed to better understand how growth regulation strategies interact with cool-season species composition during overseeding.

The present study was conducted to evaluate the combined effects of different cool-season turfgrass species and cultivars and fall-applied TE on overseeding success, winter turf quality, and spring transition performance of hybrid bermudagrass under Mediterranean climatic conditions. By providing a species- and cultivar-level assessment of TE-mediated growth regulation, this study aims to offer practical, region-specific guidance for optimizing overseeding strategies and improving year-round turfgrass performance in warm-season turf systems.

MATERIAL AND METHOD

The study was conducted on four-year-old hybrid bermudagrass (*Cynodon dactylon* × *C. transvaalensis*) ‘Tifway’ at the Ornamental Plants Research and Application Field of Akdeniz University between October 2023 and May 2024. The experiment was conducted as a 2 × 5 factorial arrangement in a randomized complete block design with three replications. The two experimental factors consisted of trinexapac-ethyl (TE) application at two levels (0 and 35 mg m⁻²) and five cool-season turfgrass cultivars: *L. perenne* ‘Solstice’ and ‘Peri’, *P. pratensis* ‘Baron’ and ‘Volt’, and *F. arundinacea* ‘Titanium’. In addition to the factorial treatment combinations, non-overseeded control plots with and without TE application were included for comparative purposes. TE was applied as a 120 g a.i. L⁻¹ emulsifiable concentrate, and the selected application rate was based on previous bermudagrass overseeding and management studies utilizing trinexapac-ethyl (Deaton and Williams, 2010; Severmutlu et al., 2012a, 2012b). The study consisted of 36 plots, each measuring 1.5 × 1.5 m.

Seeding rates varied among species, with *L. perenne* sown at 100 g m⁻², *P. pratensis* at 20 g m⁻², and *F. arundinacea* at 90 g m⁻². Seeding rates were determined based on previous turfgrass establishment and overseeding studies and were adjusted according to species-specific differences in seed size and establishment characteristics to ensure rapid establishment and uniform winter turf cover (Severmutlu et al., 2005; Özkan & Kır, 2023; Minner et al., 2008). Spray application of TE (Primo MAXX, Syngenta Crop Protection, Greensboro, NC, USA; 120 g a.i. L⁻¹ emulsifiable concentrate) was made on October 13, 2023 using a backpack sprayer calibrated to deliver 800 L ha⁻¹ (Severmutlu et al., 2012b). Six days after application, bermudagrass was mowed to a height of 1.5 cm, and a double-sided verticutting operation was performed at a 1.5 cm depth to suppress bermudagrass growth, open the turf canopy, improve seed-to-soil contact, and facilitate the germination and establishment of the newly sown seeds. Subsequently, cool-season turfgrass seeds were evenly sown onto the plots and covered with topsoil. Plots were then irrigated regularly to maintain adequate surface moisture and to prevent seed desiccation during germination and establishment. Turfs were fertilized immediately after overseeding at a rate of 5 g N m⁻² using a fertilizer containing 20N–8.8P–16.6K. Additional nitrogen applications were made in November and December using ammonium sulfate, each at a rate of 5 g N m⁻². The first mowing was performed when the turf reached a height of 4.5 cm, and the turf was mowed to 3 cm, following the one-third mowing rule. Thereafter, mowing was continued at a height of 3 cm throughout the study period.

Throughout the experiment, several physiological and visual parameters were monitored regularly. Normalized Difference Vegetation Index (NDVI) measurements, which reflect plant health and active growth, were taken twice a month at 20 points per plot using a FIELDSCOUT Turf Color Meter TCM 500. NDVI values range from 0.00 to 0.99, with higher values indicating healthy, stress-free plants. Relative chlorophyll content was also measured biweekly using a FIELDSCOUT CM 1000 chlorophyll meter, with 20 readings obtained per plot. Turfgrass quality was assessed twice a month using a 1–9 scale, where 9 represents excellent quality, 6 indicates acceptable quality, and 1 corresponds to poor quality (completely yellow or dead grass) (Morris and Shearman, 1998). The percentage of green turf coverage in each plot was determined on a 0–100% scale, with 0% indicating complete dormancy with no green tissue and 100% representing full coverage by healthy green turf.

The study area is characterized by a typical Mediterranean climate. Selected climatic parameters of the study area are presented in Table 1. During the experimental (October 2023- May 2024), minimum air temperatures reached -0.47 °C during the winter months, whereas maximum temperatures increased progressively during spring, reaching 33.77 °C in May 2024. Precipitation remained generally low during the study period, with the highest monthly total recorded in January 2024 (122.76 mm). Relative humidity was higher during winter and gradually declined toward late spring, ranging from 77.35% in January 2024 to 58.15% in May 2024. Mean wind speed remained relatively stable throughout the experimental period, varying between 1.68 and 2.61 m s⁻¹.

Table 1. Meteorological parameters during the experimental period recorded at the Konyaaltı Weather Station in Antalya, Turkey

Months	Mean air temperature (°C)		Precipitation (mm)	Relative humidity (%)	Wind speed (m s ⁻¹)
	min	max	mean	mean	mean
Oct 2023	14.01	31.79	16.41	54.37	1.68
Nov 2023	0.65	27.64	112.76	75.21	2.61
Dec 2023	3.85	20.42	112.65	76.98	1.83
Jan 2024	-0.47	17.95	122.76	77.35	2.43
Feb 2024	1.98	20.93	80.74	75.58	1.85
Mar 2024	1.5	25.75	73.13	69.22	1.94
Apr 2024	9.12	28.92	7.73	61.98	2.04
May 2024	9.93	33.77	30.27	58.15	1.92

All collected data were analyzed according to the designated experimental design. Analysis of variance (ANOVA) was performed using the PROC GLM (SAS Institute, 1999). Biweekly measurements collected throughout the winter and spring periods were pooled within each season, and seasonal mean values were subjected to statistical analysis. Means were separated using Fisher's Least Significant Difference (LSD) test at a significance level of 0.05.

RESULTS AND DISCUSSION

During the fall–winter period, the TE × cultivar interaction was not statistically significant, and the main effect of TE application was also not significant. However, the cultivar main effect was significant. In contrast, during the spring transition period, significant TE × cultivar interactions were detected for turf quality and NDVI values, whereas no significant interaction was observed for relative chlorophyll content or green grass cover. Although TE tended to improve turf performance, its effects were not sufficiently pronounced to reach statistical significance under fall–winter conditions. The limited impact of TE during this period may be attributed to incomplete physiological activity. At the time of application, bermudagrass was growing slowly and had begun to enter dormancy within one week, which likely reduced TE metabolism and, consequently, limited its suppressive effects. The literature also indicates that plant growth regulators, including TE, may have limited efficacy at low temperatures and do not contribute significantly to visual quality or turf color, particularly during winter dormancy (Fagerness & Yelverton, 2000; Fagerness et. al., 2002).

In contrast, significant differences were observed among cool-season turfgrass cultivars in terms of overall turfgrass quality during the fall–winter period. Plots overseeded with *L. perenne* ‘Peri’ and *F. arundinacea* ‘Titanium’ exhibited the highest fall–winter mean turf quality values, with ratings of 7.5 and 7.2, respectively, whereas both *P. pratensis* L. cultivars failed to achieve acceptable quality levels based on their fall–winter mean values (Table 2). When averaged across TE treatments, fall–winter turf quality ratings of overseeded plots ranged from 7.5 (*L. perenne* ‘Peri’) to 5.4 (*P. pratensis* ‘Baron’) and were significantly higher than those of the non-overseeded control, which attained a mean quality rating of 3.9.

Table 2. Turfgrass quality parameters of bermudagrass plots overseeded with different cool-season turfgrasses, with and without trinexapac-ethyl (TE) application across fall–winter and spring seasons.

Species/variety name	Overall Turfgrass Quality (1-9 scale)*					
	Fall-Winter			Spring		
	TE	TE	TE	TE	TE	TE
	none	exist	mean	none	exist	mean
<i>P. pratensis</i> 'Volt'	5.6	5.7	5.6 bc ¹	5.3 d	5.9 cd	5.6
<i>P. pratensis</i> 'Baron'	5.4	5.5	5.4 c	5.4 d	5.5 d	5.5
<i>L. perenne</i> 'Solstice'	6.2	6.5	6.4 b	5.6 d	6.6 c	6.2
<i>L. perenne</i> 'Peri'	7.3	7.7	7.5 a	7.5 ab	8.2 a	7.9
<i>F. arundinacea</i> 'Titanium'	6.9	7.3	7.2 a	7.0 bc	7.4 b	7.2
Control (Non overseeded)	3.8	4.0	3.9 d	3.6 f	4.5 e	4.1
Mean	5.8 A	6.1 A		5.7 B	6.4 A	

* Turfgrass quality was assessed twice a month using a 1–9 scale, where 9 represents excellent quality, 6 indicates acceptable quality, and 1 corresponds to poor quality.

¹Means followed by the same uppercase letters within rows or the same lowercase letters within columns are not significantly different according to Fisher’s LSD test at the 0.05 probability level. Statistical comparisons were performed separately within each experimental period (fall–winter and spring). During the fall–winter period, the TE × Cultivar interaction was not significant; therefore, TE and species means are presented separately. During the spring period, the TE × species interaction was significant, and treatment comparisons were made based on interaction means.

Consistent trends observed in relative chlorophyll content and NDVI measurements further validated the visual turf quality assessments (Tables 3 and 4). During the fall–winter period, overseeded plots exhibited substantially higher relative relative chlorophyll content and NDVI values than the non-overseeded control. Overseeded plots exhibited up to 89 % higher relative chlorophyll content and up to 116% higher NDVI values compared with the non-overseeded control plots. The highest fall–winter relative relative chlorophyll content values were recorded in *F. arundinacea* ‘Titanium’ and *L. perenne* ‘Peri’, with values of 242 and 236, respectively, compared with 128 in the non-overseeded control. Similarly, the highest fall–winter NDVI values were recorded in *L. perenne* ‘Peri’ and *F. arundinacea* ‘Titanium’ with values of 0.740 and 0.727, respectively, whereas the non-overseeded control had and NDVI value of 0.342. These results indicate that cool-season grass species were able to maintain active photosynthetic tissue and higher metabolic activity during the fall and winter periods compared with non-overseeded hybrid bermudagrass (control plots).

Table 3. Relative chlorophyll content of bermudagrass plots overseeded with different cool-season turfgrasses, with and without trinexapac-ethyl (TE) application across fall–winter and spring seasons.

Species/varieties	Relative chlorophyll content					
	Fall-Winter			Spring		
	TE	TE		TE	TE	
	none	exist	mean	none	exist	mean
<i>P. Pratensis</i> 'Volt'	175	185	180 b ¹	160	175	168 b
<i>P. Pratensis</i> 'Baron'	170	180	175 b	158	166	163 b
<i>L. Perenne</i> 'Solstice'	190	199	195 b	165	180	173 b
<i>L. Perenne</i> 'Peri'	230	243	236 a	185	220	203 a
<i>F. arundinacea</i> 'Titanium'	236	247	242 a	180	210	195 a
Control (Non overseeded)	132	124	128 c	128	155	142 c
Mean	189 A	196 A		162 B	184 A	

¹Means followed by the same uppercase letters within rows or the same lowercase letters within columns are not significantly different according to Fisher's LSD test at the 0.05 probability level. Statistical comparisons were performed separately within each experimental period (fall–winter and spring). During both the fall–winter and spring periods, the TE × cultivar interaction was not significant; therefore, TE and cultivar means are presented separately.

Table 4. NDVI values of bermudagrass plots overseeded with different cool-season turfgrasses, with and without trinexapac-ethyl (TE) application across fall–winter and spring seasons.

Species/varieties	NDVI values					
	Fall-Winter			Spring		
	TE	TE		TE	TE	
	none	exist	mean	none	exist	mean
<i>P. pratensis</i> 'Volt'	0.678	0.684	0.681 bc	0.550 d	0.568 cd	0.559
<i>P. pratensis</i> 'Baron'	0.670	0.680	0.675 c	0.550 d	0.560 d	0.555
<i>L. perenne</i> 'Solstice'	0.690	0.716	0.703 b	0.569 cd	0.605 bc	0.587
<i>L. perenne</i> 'Peri'	0.734	0.746	0.740 a	0.618 b	0.675 a	0.647
<i>F. arundinacea</i> 'Titanium'	0.718	0.735	0.727 a	0.610 b	0.660 a	0.635
Control (Non overseeded)	0.345	0.338	0.342 d	0.412 e	0.510 f	0.491
Mean	0.644 A	0.650 A		0.551 B	0.596 A	

¹Means followed by the same uppercase letters within rows or the same lowercase letters within columns are not significantly different according to Fisher's LSD test at the 0.05 probability level. Statistical comparisons were performed separately within each experimental period (fall–winter and spring). During the fall–winter period, the TE × Cultivar interaction was not significant; therefore, TE and species means are presented separately. During the spring period, the TE × species interaction was significant, and treatment comparisons were made based on interaction means.

In agreement with Rossini et al. (2019), the present study demonstrated significant differences in turf performance among cool-season turfgrass species and cultivars used for overseeding. The superior performance of *L. perenne* and *F. arundinacea* cultivars agrees with previous studies reporting that *L. perenne* is characterized by rapid establishment, high turf density, and improved winter turf quality when overseeded into dormant bermudagrass, whereas *F. arundinacea* can maintain acceptable turf performance under low-temperature conditions due to its physiological adaptation capacity (Mazur and Rice, 1999; Richardson et al., 2007; Manuchehri et al., 2014). In contrast, the relatively poor turf quality observed in

plots overseeded with *P. pratensis* can be attributed to its slower germination and establishment rates, which limit its competitive ability against bermudagrass. This response is consistent with previous studies reporting that *P. pratensis* establishes more slowly and requires a longer period to achieve full turf cover than *L. perenne* under overseeding and turf establishment conditions (Minner et al., 2008; Proctor et al., 2015).

Fall applications of TE enhanced the spring transition of bermudagrass as evidenced by higher turf quality, NDVI, and chlorophyll values in both overseeded plots and non-overseeded control, compared with untreated respective plots in spring (Table 2, 3, and 4). Similarly, Richardson (2002) reported that sequential TE applications in August, September, and October advanced spring green-up by approximately 10 days in 'Tifway' bermudagrass relative to untreated plots. This earlier and improved spring transition may be attributed to increased soluble carbohydrate availability in early spring, resulting from reduced consumption of fixed carbohydrates during the fall due to suppressed growth following TE application. Han (1998) also observed elevated total carbohydrate levels in *Agrostis stolonifera* L. after TE treatment and suggested that reduced leaf growth limits carbohydrate consumption, allowing photosynthates to be stored for later use. Warm-season grasses generally break dormancy in spring when soil temperatures exceed 10 °C (Beard, 1973). During this transition period, new growth is initiated from the nodes of stolons, rhizomes, and crown meristems, while carbohydrate reserves are mobilized into soluble sugars to support the emergence of the first new leaves. Together, these physiological responses likely explain the enhanced spring performance observed in TE-treated plots. During the spring period, a significant TE × cultivar interaction was detected for turf quality and NDVI values reflecting a cultivar-dependent response to TE application (Table 2 and 4). With the exception of cultivars of *P. pratensis*, TE application prior to overseeding significantly enhanced turfgrass quality and NDVI across all cultivars in spring (Tables 2–4). The highest turf quality rating (8.2) was recorded in plots receiving TE application followed by overseeding with *L. perenne* 'Peri'. When averaged across TE treatments, mean spring quality ratings of overseeded plots ranged from 7.9 to 5.5 and were consistently higher than those of the non-overseeded control, which attained a mean quality rating of 4.1 (Table 2). Similar to winter season none of the *P. pratensis* L. cultivars acceptable quality in spring. NDVI and chlorophyll measurements closely aligned with turf quality evaluations (Table 3 and 4), further confirming NDVI as a reliable physiological indicator for assessing winter turf performance. Previous turfgrass studies have also demonstrated strong relationships between NDVI and turf quality, green tissue proportion, and canopy greenness; furthermore, NDVI has been reported to be closely associated with visual turf quality differences among cool-season turfgrass species and cultivars (Richardson et al., 2002; Bremer et al., 2011a, 2011b).

As a result, NDVI has been widely adopted as an objective metric of turf performance, particularly in research addressing overseeding practices, winter color retention, and stress tolerance. For example, Rossini et al. (2019) evaluated cool-season grass species used for overseeding on sports fields using NDVI in conjunction with leaf texture, vertical growth, and yield parameters, concluding that NDVI effectively reflected species performance under suboptimal environmental conditions. Similarly De Luca and Gómez de Barreda (2021) employed combined NDVI and visual assessments to monitor fall color retention and spring green-up dynamics in bermudagrass.

Bermudagrass entered dormancy in December, rapidly losing green color and turf quality. The green cover percentage is an essential indicator of functional performance and user

expectations during this dormant period. Overall, overseeding with cool-season turfgrass cultivars substantially improved turfgrass performance by maintaining an average of 96–77% active green cover throughout the winter and spring periods. In contrast, non-overseeded control plots sustained only approximately 54% green cover when averaged across TE treatments (Table 5). *L. perenne* and *F. arundinacea* cultivars provided approximately 90% green turf coverage during the winter–spring period. Moreover, TE application prior to overseeding improved green cover in all cultivars during the spring transition period. The greatest increase was observed in *P. pratensis* ‘Volt’, where green cover increased from 68% to 85%, corresponding to an improvement of approximately 25% compared with the respective non-treated plots, likely due to enhanced bermudagrass spring transition (Table 5). Collectively, these findings indicate that overseeding bermudagrass with cool-season grasses, in combination with fall TE application, represents an effective management strategy for maintaining acceptable turf quality, visual greenness, and functional playability during the winter–spring period.

Table 5. Green grass cover (%) of bermudagrass plots overseeded with different cool-season turfgrasses, with and without trinexapac-ethyl (TE) application during Winter–Spring (December–April).

Species/variety name	Green Grass Cover (%)		
	Winter-Spring (December–April)		mean
	none	TE exist	
<i>P. pratensis</i> 'Volt'	68	85	77 b
<i>P. pratensis</i> 'Baron'	72	86	79 b
<i>L. perenne</i> 'Solstice'	89	95	92 a
<i>L. perenne</i> 'Peri'	93	98	96 a
<i>F. arundinacea</i> ‘Titanium’	89	96	93 a
Control (Non overseed)	45	61	54 c
Mean	77 B	87 A	

¹Means followed by the same lowercase letter within columns are not significantly different among species/varieties, and means followed by the same uppercase letter within the Mean row are not significantly different between TE treatments according to Fisher’s protected least significant difference (LSD) test ($\alpha = 0.05$).

In a related study, Aldahir et al. (2015) reported that overseeding bermudagrass with cool-season species, in combination with plant growth regulator applications, significantly improved winter turf quality and surface uniformity across different climatic conditions. Their results indicated that higher overseeding rates and the use of TE were particularly effective in enhancing turfgrass quality, suppressing undesirable species, and maintaining visual uniformity during the winter period. Similarly, Deaton and Williams (2010) found that overseeding significantly improved the appearance of sites where bermudagrass had entered dormancy, thereby ensuring the persistence of winter green cover. Importantly, TE application improved turf performance without inducing phytotoxic effects on overseeded cool-season grasses. Collectively, these findings are consistent with the results of the present study and further support the suitability of TE as an effective growth-regulation strategy in overseeding systems.

Numerous studies conducted in recent years have demonstrated that TE and other plant growth regulators positively influence turfgrass density, uniformity, and color, supporting their effective use in turfgrass management. For instance, Pornaro et al. (2017) reported that TE application to low-input turf systems across three turfgrass species significantly reduced shoot growth while simultaneously improving visual quality and color. Similarly, Serena et al. (2018) found that, in bermudagrass, the combined application of TE and a soil wetting agent enhanced turf quality, percent cover and NDVI values under water stress conditions.

Although *F. arundinacea* ‘Titanium’ exhibited comparable NDVI values and turf quality to *L. perenne* ‘Solstice’ during the winter months, its coarser leaf texture and high heat tolerance resulted in lower quality during spring. This reflects its greater competitive potential against bermudagrass in late spring, which may pose management challenges during the summer. Previous studies have emphasized that successful overseeding management should consider both rapid winter establishment and the ease of spring transition back to bermudagrass, because species selection strongly influences this process (Serensits et al., 2011; Sciusco et al., 2024). Therefore, effective overseeding management should consider not only winter performance but also species-specific competitive dynamics during the spring transition, particularly for highly competitive species such as *F. arundinacea*.

CONCLUSION

This study provides practical guidance for optimizing overseeding practices in Mediterranean and warm-temperate turfgrass systems. Overall, overseeding bermudagrass with cool-season grass cultivars significantly improved winter and spring turf performance by maintaining higher green cover, NDVI, relative chlorophyll content, and visual quality compared with non-overseeded controls. Among the tested cultivars, *L. perenne* ‘Peri’ consistently demonstrated the highest overall performance, combining rapid establishment, superior winter quality, and effective spring transition, making it a particularly suitable for overseeding programs. *F. arundinacea* ‘Titanium’ also performed well in winter; however, its competitive growth during spring may interfere with bermudagrass recovery, whereas *P. pratensis* cultivars exhibited slower establishment and comparatively lower turf quality. Fall-applied TE further enhanced bermudagrass spring transition and green cover, although its effects during winter were limited under low-temperature conditions due to reduced physiological. These findings demonstrate that combining overseeding with cool-season turfgrass species and TE application can be an effective strategy for maintaining functional turf performance, visual greenness, and playability throughout the winter–spring period. Nevertheless, careful selection and management of highly competitive species, such as *F. arundinacea*, are necessary to avoid delayed bermudagrass recovery and potential summer management challenges.

AUTHOR CONTRIBUTIONS

Hüseyin Polat and Batuhan Kaymak: Contributed to fieldwork. **Ahmet Karaçan:** Conducted literature review for the article. **Bahar Sancar:** Participated in writing the article. **Songül Sever Mutlu:** Contributed original ideas, study design, data analysis, and article writing. All authors discussed the results and contributed to the final version of the article.

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The authors declare no conflict of interest.

ETHICS COMMITTEE APPROVAL

This study does not require an ethics committee approval

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