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False-green kyllinga competitiveness from seed in turfgrass

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Abstract

False-green kyllinga (FGK; *Kyllinga gracillima* Miq.) is a warm-season perennial weed in the Cyperaceae family. Our objective was to determine the potential for FGK to establish from seed in turfgrass. Replicated field experiments were conducted in Kentucky bluegrass (*Poa pratensis* L.) mowed at 6 cm. FGK was seeded at 5 or 500 kg ha^{-1}, and smooth crabgrass [*Digitaria ischaemum* (Schreb.) Schreb. Ex Muhl.] was seeded at 500 kg ha^{-1}. Turf was managed under either low or high input programs to generate swards of different density. Low-input turfgrass received 25 kg N ha^{-1} annually, while high-input turfgrass received 200 kg N ha^{-1} annually along with preventative fungicide applications. FGK establishment from seed was reduced more by turfgrass inputs than smooth crabgrass. Smooth crabgrass cover in September of both experiments was >93% and not affected by turfgrass inputs. When FGK was seeded at 500 kg ha^{-1}, cover in September was higher in low input (57% in Run 1, 59% in Run 2) than in high input turf (36% in Run 1, 18% in Run 2). When FGK was seeded at the lower rate of 5 kg ha^{-1}, cover in Run 1 was higher in the low input (14%) than high input turf (2%), but FGK cover was similar between input levels in Run 2, with 4 and 1% cover in the low and high input plots, respectively. FGK successfully overwintered in this study, with cover increasing during the second summer of growth. Although FGK is less competitive as a seedling than smooth crabgrass, its perennial life cycle allows it to increase weed cover over time.

Plain Language Summary

False-green kyllinga is a troublesome weed in cool-season turfgrass, and little is known about how it establishes from seed. This study compared its establishment to smooth crabgrass in turfgrass maintained under different management levels. We found that high-input turfgrass, which is denser due to fertilization, reduced false-green kyllinga establishment but did not prevent it. Although false-green kyllinga seedlings were less competitive than smooth crabgrass, they survived winter and expanded in the second year. This means that while maintaining dense turf can help

Abbreviation: FGK, false-green kyllinga.

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limit false-green kyllinga, it will not stop it from establishing and spreading. Because of its perennial nature, false-green kyllinga can gradually take over turfgrass areas. Future research should explore the influence of preemergence herbicides and other nonchemical control practices to better manage this weed.

1 | INTRODUCTION

False-green kyllinga (FGK; *Kyllinga gracillima* Miq.) is a C_4 perennial weed in the Cyperaceae family that is challenging to control, especially in cool-season turfgrass (Bryson et al., 1997). FGK produces an extensive rhizome system that often results in a dense mat, which crowds out desirable cool-season turfgrass, causing an uneven and nonuniform playing surface (Bryson et al., 1997). It is more prevalent in areas of high volumetric water content, such as irrigated turfgrass, and can produce seed at mowing heights as low as 1.3 cm (Bryson & Carter, 2008; Bryson et al., 1997; McElroy, Yelverton, Burton, et al., 2005).

Limited research exists on FGK seed and seedling biology. Bryson et al. (1997) describes collections of fruiting FGK that have been dated from late August to frost, which suggests that FGK flowering relies on a short-day photoperiod. The pollination needs of FGK have not been investigated, but most sedges are thought to be allogamous (Brown & Marshall, 1981; Bryson & Carter, 2008). Green kyllinga (*Kyllinga brevifolia* Rottb.) and FGK are almost impossible to discern from one another unless the achenes are examined (Bryson & Carter, 2008). Green kyllinga achenes have a toothed keel, whereas FGK seeds have a smooth keel (Bryson et al., 1997). Green kyllinga seeds float (Kern, 1974), are disseminated by wind and water, and germinate without aging (Sumaryono & Basuki, 1986), which aligns with our anecdotal observations of FGK seed buoyancy in the laboratory. FGK requires fluctuating day/night temperatures to germinate, and germination is enhanced by light (Amgain et al., 2024). Temperature requirements for the two species are similar; FGK germinates well at alternating temperatures of 20/10°C and warmer but does not germinate at 15/5°C, while green kyllinga germination occurs at temperatures between 20°C and 24°C and is limited at 14°C to 17°C (Amgain et al., 2024; Molin et al., 1997). Planting depth effects on FGK have not been studied, but depth influences green kyllinga and cock's comb kyllinga (*Kyllinga squamulata* Thonn. Ex Vahl) emergence (Molin et al., 1997). Green kyllinga seed emergence was 60% when planted at the soil surface, 20% when planted at 0.5 cm, and emergence ceased at >2 cm (Molin et al., 1997). Cock's comb kyllinga emergence from seed is sensitive to planting depth, as emergence is modeled to decrease from 64% at 0.5 cm to 15% at 2.0 cm and just 2% at 4.0 cm (Hoyle et al., 2013). Green kyllinga is not likely affected by soil pH, as seedling emergence was the same in buffer solutions ranging from pH 5.5 to 9.5, but germination is reduced at low water potentials (Molin et al., 1997).

While FGK establishment from seed has not been investigated, Lowe et al. (2000) evaluated green kyllinga establishment from seed or stolons in established or newly sprigged hybrid Tifway bermudagrass [*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burtt-Davy] with different nitrogen fertilizer regimens at two different mowing heights. Among the factors examined, green kyllinga establishment method (seeded or stolonized) had the greatest effect in the year of establishment, as green kyllinga cover was two to four times greater when established from stolons than seed (Lowe et al., 2000). In the year following establishment, the effect of establishment method waned (Lowe et al., 2000). In established turf, there was less green kyllinga cover at the high mowing height (5.0 cm) than the low (2.5 cm) mowing height for both seed- and stolon-established green kyllinga (Lowe et al., 2000). While mowing height had a large effect on green kyllinga establishment in established turf, increasing N from 0 to 49 kg ha^{-1} m^{-1} did not consistently or substantially affect green kyllinga encroachment in established or newly sprigged turf (Lowe et al., 2000). While FGK establishment from seed into cool-season turfgrass has not been investigated, anecdotally, we have observed practitioners achieve visible FGK control with postemergence herbicides, but the infestation returns a year or two later. This suggests that the reinfestation could be established from seed in the soil seedbank.

Practitioners typically rely on the postemergence herbicides sulfentrazone, halosulfuron-methyl, and imazosulfuron for FGK control in cool-season turfgrass (Elmore et al., 2019). Sequential applications of these herbicides are often required for acceptable FGK control (Elmore et al., 2019; Gannon et al., 2012; McElroy, Yelverton, & Warren, 2005). In cool-season turfgrass a single application of imazosulfuron (0.42 and 0.74 kg ha^{-1}) and sequential applications of halosulfuron-methyl (0.07 kg ha^{-1}) provided more control than single or sequential applications of sulfentrazone (0.14 kg ha^{-1}) (Elmore et al., 2019). The combination of postemergence herbicides with a turf-type tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort., nom. Cons.] interseeding increased control compared to herbicides or seeding alone (Elmore & Tuck, 2022). For example, halosulfuron-methyl (0.07 kg ha^{-1}) applied without interseeding resulted in 62% FGK cover, whereas when coupled with interseeding,

FGK cover was 6% (Elmore & Tuck, 2022). Postemergence herbicide applications focus on controlling existing rhizomes (Elmore et al., 2019; Gannon et al., 2012; McElroy, Yelverton, & Warren, 2005), whereas the potential establishment of the remaining *Kyllinga* spp. seed in the seedbank has received limited investigation.

The objective of this experiment was to evaluate FGK establishment from seed compared to smooth crabgrass (*Digitaria ischaemum* (Schreb.) Schreb. Ex. Muhl.) in Kentucky bluegrass subjected to low and high input management regimens designed to produce turfgrass swards of different density. We hypothesized that FGK will establish less readily in high-density turfgrass and will not establish as readily as smooth crabgrass.

Core Ideas

- False-green kyllinga and smooth crabgrass established from seed in mature Kentucky bluegrass.
- False-green kyllinga establishment was more strongly suppressed by high-input turf management than smooth crabgrass.
- Smooth crabgrass cover was largely unaffected by turfgrass input level.
- False-green kyllinga overwintered successfully and increased in cover the subsequent summer.

2 | MATERIALS AND METHODS

2.1 | Site conditions

A field experiment was repeated in time on adjacent sites at Rutgers Hort Farm No. 2 in North Brunswick, NJ, from 2021 to 2022 (Run 1) and 2022 to 2023 (Run 2). Experiments were conducted on Kentucky bluegrass established from sod on October 20, 2020, and October 28, 2021. The sod was established from seed with Bluenote, Legend, and Bolt (40:40:20 v/v). Kentucky bluegrass was grown on an Evesboro loamy sand (mesic, coated Lamellic Quartzipsamment) at Tuckahoe Turf Farms. In both years the 11-month-old sod was cut to a depth containing 1 cm of native soil and placed within 24 h over a Nixon sandy loam (fine-loamy, mixed, semiactive, and mesic Typic Hapludult) with a pH of 6.2% and 2.2% organic matter. Prior to sodding, the existing turf was cut with a sod cutter to a depth of 5 cm. Turf was removed to prepare the site for sod. Previously, the site had been maintained as a tall fescue stand with no FGK and a moderate crabgrass (*Digitaria* spp.) infestation (~50% crabgrass cover in late summer) for several years with no preemergent use. After sodding, the site was mowed once weekly during the entire study period at 6 cm using a walk-behind rotary mower (Toro Recycler, Toro), and clippings were collected, including when seedheads were visible. Plots were irrigated with overhead irrigation as needed to optimize plant growth and periodically monitored using a moisture probe (FieldScout TDR 350, Spectrum Technologies). A wetting agent (TriCure, Mitchell Products) was applied on May 22, 2021, and May 20, 2022, at 13 L ha^{-1} to ensure complete and uniform wetting of the soil during the expected period of weed seed germination and establishment.

2.2 | Experimental design and treatments

Treatments consisted of two turfgrass input programs and three weed seeding treatments arranged in a split-plot randomized complete block design with four blocks. The turfgrass input programs were designed to create consistent differences in turfgrass density with contrasting, real-world maintenance scenarios for cool-season lawns. The high input program (200 kg N ha^{-1} annually with preventative fungicides) aligns with local Extension recommendations for Kentucky bluegrass for a high-maintenance lawn (Heckman & Murphy, 2003). In contrast, the low input program (25 kg N ha^{-1} annually with no fungicides) reflects minimal-care conditions, common in lower maintenance or budget-restricted landscapes. The two input programs formed whole plots. Three sub-plot (1.1 by 2.0 m) treatments were FGK seeded at 5 kg or 500 kg ha^{-1}, and smooth crabgrass (*Digitaria* spp.) at 500 kg ha^{-1}. Seeding rates were selected to simulate two relevant scenarios. The 5 kg ha^{-1} rate was designed to simulate seed introduced by mowing equipment or foot traffic. The 500 kg ha^{-1} rate was designed to approximate the seed produced by severe FGK infestation. This was determined by counting the number of achenes (seeds) from 10 random spikelets and the number of spikelets in a 0.3 by 0.3 m area. Smooth crabgrass was used as a standard for comparison, as it is a prevalent and important summer annual weed species of turfgrass that is very competitive from seed (Kim et al., 2002). Additionally, the effect of turfgrass management practices on crabgrass establishment is well studied (reviewed by Busey, 2003; Hahn et al., 2020; Vuković et al., 2025). Moreover, smooth crabgrass and FGK are both prolific seed producers and are C_4 species, which grow more rapidly than cool-season turfgrass in the high temperatures of summer (Beard, 1973; Peters & Dunn, 1971).

TABLE 1 Fertilizer and fungicide applied to Kentucky bluegrass in North Brunswick, NJ for two different turfgrass input programs in 2021–2022 (Run 1) and 2022–2023 (Run 2).

Turfgrass input program	Product	Rate	Application date	
			Run 1	Run 2
Low	26-0-5[a]	25 kg N ha^{-1}	June 24, 2021	June 22, 2022
High	26-0-5	50 kg N ha^{-1}	April 16, May 20, June 24, and September 29, 2021 May 20 and June 22, 2022	April 5, May 20, June 22, and September 26, 2022 May 29 and June 26, 2023
	Azoxystrobin + difenconazole[b]	0.9 + 0.6 kg ha^{-1}	May 20, July 1, and Au. 18 2021 May 20 and June 16, 2022	May 20, June 16, and Aug. 2, 2022[c]

Note: Programs were designed to produce a dense turf canopy (high input) and a moderately dense canopy typical of a low maintenance program (low input).

[a]Country Club 26-0-5, 50% of N from methylene urea, SGN 150 (Lebanon Turf,) was applied using a shaker jar. Fertilizer was irrigated with 0.5 cm water immediately after application.

[b]Briskway (Syngenta Professional Products, Greensboro, NC) was applied with a CO_2-powered backpack sprayer equipped with an AI9504EVS nozzle (Teejet Technologies Springfield) with 420 L ha^{-1} of water carrier at 310 kPa.

[c]Conditions were not conducive for disease development in Run 2 prior to the conclusion of the experiment in early July 2023; thus, no fungicides were applied.

2.3 | Weed seed collection

Smooth crabgrass and FGK seed were collected from adjacent fields at Hort Farm No. 2 by pulling a leaf sweeper (Agri-Fab Tow Behind Lawn Sweeper, Agri-Fab, INC) through designated fields when seeds were ripe. FGK seeds were harvested in autumn 2020, and smooth crabgrass seeds were harvested in autumn 2017. After harvest, seeds were dried at 30°C for 48 h in a convection oven and then stored in a refrigerator at 2°C. Seed germination was evaluated in the laboratory on Petri dishes, containing filter paper in July 2021. Water (10 mL) was added to each Petri dish and then dishes were wrapped in Parafilm; additional water was added as needed to maintain moisture. Petri dishes were kept under 24 h light (70–100 μE m^{-2} s^{-1}) at a temperature of 20°C–24°C (Molin et al., 1997). After 10 days, seeds, were evaluated for radicle emergence. Germination was 67% and 52% for smooth crabgrass and FGK, respectively.

On January 18, 2021, and February 9, 2022, the separate plot areas for Run 1 and Run 2, respectively, were seeded. Plots were scarified (Ren-O-Thin Power Rake, RYAN) to a depth of 0.5 cm, and debris was removed. Two passes with the scarifier were applied to high input plots to maintain a thick turf stand in spring, while four passes were applied to the low input plots to help produce a thinner turf stand. Smooth crabgrass and FGK were then seeded using shaker jars. The site was then topdressed with silica sand to a depth of 0.25 cm.

2.4 | Turfgrass input programs

The high input program consisted of four applications of 50 kg N ha^{-1} totaling 200 kg N ha^{-1} per year (Table 1) and fungicides applied to prevent diseases common to Kentucky bluegrass, including summer patch (*Magnaporthiopsis poae*), brown patch (*Rhizoctonia solani*), and dollar spot (*Clariireedia jacksonii*). The low input program consisted of one 25 kg N ha^{-1} fertilizer application per year and no fungicide applications. The fertilizer source was a 26N-0P_2O_5-5K_2O fertilizer with 50% of N slowly available from methylene urea and 50% readily available from urea. Fenoxaprop-p-ethyl (Acclaim EXTRA, Bayer Environmental Science) was applied at 0.045 kg ha^{-1} to all FGK-seeded plots to control leaf-stage crabgrass seedlings that had emerged across the site. Fenoxaprop-p-ethyl was applied to Run 1 on June 25, 2021, July 7, 2021, June 16, 2022, and July 14, 2022. Run 2 application dates were June 16, 2022, and July 14, 2022. Applications were made using the same methods described for the fungicide application in Table 1. There were no observable effects of fenoxaprop-p-ethyl on FGK. MCPA + mecoprop-p + dicamba + carfentrazone-ethyl (1.458 + 0.303 + 0.146 + 0.022 kg ha^{-1}; PowerZone, PBI Gordon Corporation) was applied on May 1, 2023, to control broadleaf weeds. Unintended short-term phytotoxicity to FGK was observed from this broadleaf herbicide application and may explain the reduced FGK cover in July 2023 compared to July 2022.

2.5 | Data collection

Weed cover was determined by visually estimating cover on a 0 (no cover) to 100 (complete cover) percent scale in July, August, and September each year and using a grid intersect count on the same dates. The grid intersect count consisted of 135 intersects evenly spaced within a 0.9 by 0.9 m area. The presence or absence of a weed was determined under each intersect and count data were converted to percent weed cover. Digital images were captured in May to document turfgrass canopy conditions at the time of FGK germination and to

validate visual canopy assessments. Green cover was quantified using image analysis software and subjected to statistical analysis. Images were captured with a Canon (Canon Eos Rebel T6i, Canon, Inc.) camera attached to a 0.6 by 0.6 m enclosed steel box equipped with four 1200 lumen, 19 watt, 5500 K white light bulbs (BlueMax HD Lighting). Photo settings consisted of an RGB color model, 8 depth, 96 DPI height, 96 DPI width, 1 orientation, 818 pixel height, and 662 pixel width. Total turfgrass cover was determined by digital image analysis with Turf Analyzer software (threshold set to hue: 46–195, saturation: 6–100, brightness: 0–100) to determine percent green cover (Karcher et al., 2017). Turfgrass quality was evaluated visually on a 1 (*poor*) to 9 (*excellent*) scale, where 6 is considered acceptable (Morris & Shearman, 1998). Turfgrass quality was assessed by visually rating plots based on uniformity, density, and color from May to September. Weed cover was not ignored in turfgrass quality ratings as greater weed cover reduced uniformity and resulted in a lower turf quality rating. Counts of FGK seedlings were conducted on July 20, 2021 (Run 1) and July 20, 2022 (Run 2). Two 20-cm-diameter cores were removed from each plot, and the number of FGK seedlings in each was counted non-destructively. Cores were then returned to the corresponding plots and irrigated to prevent drought stress. Data were averaged across core subsamples prior to analysis.

2.6 | Statistical analyses

Data were subjected to analysis of variance (ANOVA) using the GLIMMIX procedure in SAS (v9.4, SAS Institute) as a split-plot randomized complete block design with turfgrass input program and weed seeding as fixed effects and replication (block) as a random effect. Fisher's protected least significant difference (LSD; $\alpha = 0.05$) was used to separate means. Data that met assumptions of ANOVA according to the Shapiro–Wilk test for normality were not transformed. Seedling counts in Run 1 were subjected to a log transformation to improve distribution of residuals and used for post-ANOVA mean separation; nontransformed values are presented for clarity. Pearson's correlation coefficients were calculated in SAS to evaluate the relationship between grid intersect counts and visual estimates of weed cover.

3 | RESULTS AND DISCUSSION

The initial data analysis revealed significant main effect-by-year interactions for most data, except turf quality. Therefore, all data were subsequently analyzed by year, except for turf quality data, which were pooled across year.

3.1 | Turfgrass green cover

The main effect of turfgrass input program was significant in both years (data not shown). The low input program produced less turfgrass green cover in May for both runs. In May 2021 in Run 1, percent green cover was 97% in the high turfgrass density plots compared to 87% in the low turfgrass density plots (data not presented). In May 2022 in Run 2, percent green turfgrass cover was 98% and 94% for the high and low turfgrass density plots, respectively. The reason for the larger green cover difference observed between input programs in Run 1 (10%) compared to Run 2 (4%) is unknown, but our anecdotal observations suggest more N was applied at the sod farm prior to harvest in Run 2, and this increased N fertility of the transplanted sod contributed to these differences.

3.2 | FGK seedling count

Main effect interactions were significant in Run 1 and are presented (Table 2). In the low input plots, there were 31 FGK seedlings per core from 500 kg seed ha^{-1} compared to 0.1 seedlings at 5 kg ha^{-1}. Turfgrass input program did not affect seedling count at 5 kg ha^{-1} FGK, but high input plots seeded with 500 kg ha^{-1} had fewer FGK seedlings than low-density plots in Run 1. In Run 2, main and interactive effects were not significant, presumably due to overall low seedling counts, which we attribute to greater turfgrass green cover in Run 2. Reduced seedling counts with greater turfgrass density are supported by Amgain et al. (2024), who found FGK germination was reduced in darkness and Vuković et al. (2025), who reported that increasing N fertilization results in excluding more light from the soil surface.

3.3 | Weed cover

Main effect interactions were significant for both visual estimates of weed cover and grid intersect counts for most rating dates, and both are presented (Table 3). Visual estimates of weed cover were strongly correlated with grid intersect assessments (Run 1: $p < 0.001$, $r \geq 0.85$; Run 2: $p < 0.001$, $r \geq 0.90$; Table 4). With some minor exceptions, treatment differences indicated by visual estimates aligned with those determined by grid intersect counts.

3.4 | Year of establishment

Establishment of FGK from seed was influenced more by turfgrass input program than smooth crabgrass in both runs. When FGK was seeded at 500 kg ha^{-1}, the high input program

TABLE 2 Effects of false-green kyllinga seeding rate and turfgrass input program on false-green kyllinga seedling count in 2021 and 2022 in Kentucky bluegrass.

	False-green kyllinga seedlings[a]		
Turfgrass input program[b]	**FGK seeding rate kg ha^{-1}**	**Run 1 (#) July 16 2021**	**Run 2 (#) July 20 2022**
Low	5	0.1c[c]	1.4
	500	31.0a	2.4
High	5	0.4c	0.6
	500	8.0b	1.1
ANOVA			
Turfgrass input program (T)[b]		*[d]	NS
Seeding treatment (S)[e]		***	NS
T × S		**	NS

Note: The high turfgrass input program consisted of 200 kg N ha^{-1} per year and preventative fungicide application, while the low input program consisted of 25 kg N ha^{-1} per year and no fungicide. ANOVA did not include smooth crabgrass seedling counts.

[a]False-green kyllinga (FGK) seedling count data were taken by counting the number of FGK seedlings in a 20 cm diameter core. Two subsamples were counted in each plot; means presented were averaged across subsamples.

[b]Turfgrass input practices were implemented by fertilizing the high-input turfgrass plots with 200 kg N ha^{-1} per year in addition to fungicide applications. The low-input turfgrass plots received 25 kg N ha^{-1} per year and received no fungicide applications.

[c]Means followed by the same letter are not significantly different according to Fisher's Protected LSD ($\alpha = 0.05$).

[d]NS, non-significant, *, **, ***, $p \leq 0.05$, 0.01, and 0.001, respectively.

[e]Weed seeding treatments in this ANOVA consisted of false-green kyllinga (5 or 500 kg ha^{-1}) and excluded smooth crabgrass data.

reduced FGK cover compared to low inputs at all evaluation dates, except the July rating for Run 2 (Table 4). When FGK was seeded at 5 kg ha^{-1}, the high input program reduced FGK cover from August onward in Run 1, but not in Run 2, although the same non-significant trend was apparent. In September of Run 1, FGK visual cover was 2% and 36% in the high input plots when seeded at 5 and 500 kg ha^{-1}, respectively, compared to 14% and 57% in the low input plots. These reductions were comparable to the >50% reduction in green kyllinga area observed by Lowe et al. (2000) when mowing height increased from 2.5 to 5.0 cm in Tifway hybrid bermudagrass, further reinforcing the importance of maintaining a dense turfgrass canopy to suppress perennial weed establishment.

FGK seeded at 5 kg ha^{-1} yielded less weed cover than when seeded at 500 kg ha^{-1} in both high and low-input turfgrass programs in August and September of both runs (Table 4). In September of Run 2, the high and low input plots seeded with 500 kg ha^{-1} FGK had 18% and 59% visual cover, respectively, whereas when seeded with 5 kg ha^{-1} FGK, cover was 1% and 4% in the high and low input plots, respectively. Generally, FGK cover in Run 2 was less than Run 1 regardless of turfgrass inputs and weed seeding rate. This was prominent in the low-input turfgrass program, especially when FGK was seeded at 500 kg ha^{-1}, which resulted in FGK cover (73%) similar to smooth crabgrass (80%) in July of Run 1 but much less cover than FGK (2%) in Run 2. This year-to-year difference is attributed to greater turfgrass green cover in Run 2. We do not attribute this difference to reduced kyllinga seed germination after 1 year of storage at 2°C. Although germination was not re-evaluated prior to the 2022 experiment, seed from the same lot were used by Amgain et al. (2024), exhibited 98% germination at alternating 25/15°C after two additional years of storage at 21°C.

Smooth crabgrass cover was less affected by turfgrass input program, as turfgrass inputs did not affect crabgrass cover in September of either run. Smooth crabgrass cover was slightly lower in high input plots during July and August of Run 1 (2021) and again in July of Run 2 (2022). The relatively small difference in smooth crabgrass cover between input programs we observed aligns with previous findings suggesting nitrogen fertilization has limited influence on crabgrass suppression. Several studies have documented that mowing height has a larger impact on crabgrass (*Digitaria* spp.) than nitrogen fertilization rate (DeBels et al., 2012; Voigt et al., 2001; Vuković et al., 2025). Studies evaluating the effect of mowing height on smooth crabgrass cover in cool-season turf report a near linear decrease in smooth crabgrass cover as heights are increased (Busey, 2003). For example, Dernoeden et al. (1993) reported 80%, 40%, and 3% smooth crabgrass cover in tall fescue as influenced by 3 years of consecutive mowing at 3.2, 5.5, and 8.8 cm heights, respectively. Vuković et al. (2025) reported similar findings in Kentucky bluegrass turf, where they reported 52%, 13%, and 3% smooth crabgrass for mowing heights of 4.9, 7.5, and 10.2 cm, respectively. Overall, the data support the relatively high smooth crabgrass cover observed and the small difference observed between input treatments.

TABLE 3 Analysis of variance of visual and grid intersect count response to turfgrass input programs and weed seeding rate in Kentucky bluegrass in 2021–2022 (Run 1) and 2022–2023 (Run 2).

		Run 1				Run 2			
Source of variance	***df***	**12 July 2021**	**31 Aug 2021**	**30 Sep 2021**	**14 July 2022**	**14 July 2022**	**19 Aug 2022**	**19 Sep 2022**	**24 July 2023**
		Probability of significant *F* test							
		Weed cover visual (%)[a]							
Turfgrass input program (T)[b]	1	***[c]	***	**	**	**	*	***	***
Seeding treatment (S)[d]	2	***	***	**	**	***	***	***	***
T × S	2	***	***	**	NS	**	NS	***	**
		Weed cover intersect (%)[e]							
T	1	**	***	***	**	*	***	***	***
S	2	***	***	***	**	***	***	***	***
T × S	2	NS	***	***	*	NS	**	***	**

Note: Weed seeding treatments were FGK (5 and 500 kg ha^{-1}) and smooth crabgrass (500 kg ha^{-1}). The high turfgrass input program consisted of 200 kg N ha^{-1} per year and preventative fungicide application, while the low input program consisted of 25 kg N ha^{-1} per year and no fungicide. Weed cover was estimated visually and determined using grid intersect counts.

[a]Weed cover was estimated visually on a 0 (no weed cover) to 100 (complete weed cover) percent scale. Weed cover refers only to the species seeded in each treatment (i.e., false-green kyllinga or smooth crabgrass), as no other weed species were present in appreciable amounts.

[b]The low input program consisted of 25 kg N ha^{-1} year^{-1} and no fungicide, while the high input program consisted of 200 kg N ha^{-1} year^{-1} and preventative fungicides.

[c]NS, non-significant, *, **, ***, $p \leq 0.05$, 0.01, and 0.001, respectively.

[d]Weed seeding treatments consisted of false-green kyllinga (5 or 500 kg ha^{-1}) and smooth crabgrass (500 kg ha^{-1}).

[e]Weed cover was determined using a grid intersect with 135 intersected and then converted to percent cover.

TABLE 4 Effects of weed seeding rate and turfgrass input program on weed cover estimated visually and by grid intersect counts in 2021–2022 (Run 1) and 2022–2023 (Run 2) in Kentucky bluegrass.

		Run 1				Run 2			
Turfgrass input program	**Seeding treatment**	**12 July 2021**	**31 Aug 2021**	**30 Sep 2021**	**14 July 2022**	**14 July 2022**	**19 Aug 2022**	**19 Sep 2022**	**24 July 2023**
		Weed cover visual (%)[a]							
High	Smooth crabgrass (500 kg ha^{-1})	60b[b]	75b	94a	56	65b	93	93a	19b
	False-green kyllinga (5 kg ha^{-1})	0c	1d	2e	20	0c	0	1d	1c
	False-green kyllinga (500 kg ha^{-1})	8c	18c	36c	47	1c	11	18c	24b
Low	Smooth crabgrass (500 kg ha^{-1})	80a	91a	97a	93	78a	95	97a	77a
	False-green kyllinga (5 kg ha^{-1})	6c	11c	14d	56	0c	7c	4d	12bc
	False-green kyllinga (500 kg ha^{-1})	73a	86a	57b	90	2c	24	59b	78a
		Weed cover intersect (%)[c]							
High	Smooth crabgrass (500 kg ha^{-1})	33	60b	80b	69b	43	91a	87a	20bc
	False-green kyllinga (5 kg ha^{-1})	0	1d	6e	20c	0	0d	1d	2d
	False-green kyllinga (500 kg ha^{-1})	15	21c	34c	59b	0	10c	19c	23b
Low	Smooth crabgrass (500 kg ha^{-1})	58	75a	86a	84a	49	93a	93a	56a
	False-green kyllinga (5 kg ha^{-1})	6	10cd	17d	58b	0	5d	5d	10cd
	False-green kyllinga (500 kg ha^{-1})	29	81a	82ab	84a	3	29b	48b	59a
	Correlation coefficient[d]	$r \geq 0.85$				$r \geq 0.90$			

Note: The high turfgrass input program consisted of 200 kg N ha^{-1} per year and preventative fungicide application, while the low input program consisted of 25 kg N ha^{-1} per year and no fungicide.

[a]Weed cover is estimated visually on a 0 (no cover) to 100 (complete cover) scale. Weed cover refers only to the species seeded in each treatment (i.e., false-green kyllinga or smooth crabgrass), as no other weed species were present in appreciable amounts.

[b]Means separation within columns and factor, and means with same letter are not significantly different according to Fisher's protected LSD ($\alpha = 0.05$).

[c]Weed cover is determined by grid intersect count using a grid with 135 intersects and converted to percent cover.

[d]Pearson's correlation coefficient (r) explains the relationship between grid intersect count and visual estimates of weed cover. Data were analyzed by run.

TABLE 5 Effects of weed seeding treatment and turfgrass input program on turfgrass quality.

Treatment	May	Jun[a]	July 1	Aug	Sep	Oct	Nov	July 2
	Turfgrass quality[b]							
Low input[a]sxx	4.6 b[d]	5.7b	5.0b	4.6b	5.7b	4.3b	3.9b	3.9b
High input[c]	6.9a	8.0a	6.3a	5.8a	6.6a	6.2a	5.4a	5.4a
5 kg ha^{-1} false-green kyllinga	6.2a	6.8	6.8a	6.7a	7.3a	7.1a	6.4a	5.5a
500 kg ha^{-1} false-green kyllinga	6.0a	7.0	6.4a	5.8b	6.7a	5.9b	4.9b	4.7b
500 kg ha^{-1} smooth crabgrass	5.1b	6.8	3.8b	3.2c	4.4b	2.7c	2.6c	3.8c
ANOVA								
Turfgrass input program (T)[b]	***[f]	***	***	***	*	***	***	***
Seeding treatment (S)[e]	**	NS	***	***	***	***	***	***
T × S	NS	NS	NS	NS	NS	NS	NS	*

Note: The high input program consisted of 200 kg N ha^{-1} per year and preventative fungicide application, while the low input program consisted of 25 kg N ha^{-1} per year and no fungicide. Turfgrass quality ratings were visually estimated on a 1 (poor) to 9 (excellent) scale, where 6 is considered acceptable. Turfgrass quality was assessed on uniformity, color, and weed establishment. Data presented are pooled across two experimental runs.

[a]Data presented for June is only from Run 2; due to unforeseen circumstances, no data were collected in Run 1. July 1 represents the initial establishment year, and July 2 represents turfgrass quality after overwintering.

[b]Turfgrass quality ratings were evaluated monthly on a 1 (poor) to 9 (excellent) scale, where 6 is considered acceptable (Morris & Shearman, 1998).

[c]The low input program consisted of 25 kg N ha^{-1} year^{-1} and no fungicide, while the high input program consisted of 200 kg N ha^{-1} year^{-1} and preventative fungicides.

[d]Means separation within columns and factor; means with same letter are not significantly different according to Fisher's protected LSD ($\alpha = 0.05$).

[e]Weed seeding treatments consisted of false-green kyllinga (5 or 500 kg ha^{-1}) and smooth crabgrass (500 kg ha^{-1}).

[f]NS, non-significant, *, **, ***, $p \leq 0.05$, 0.01, and 0.001, respectively.

3.5 | Year after establishment

FGK successfully established by seed and interceding within the sward as a perennial after overwintering from the initial establishment year. In plots seeded at 5 kg ha^{-1}, FGK intersect cover in low-input turfgrass increased from 17% in September 2021 to 58% in July 2022. In high-input turfgrass, cover increased from 6% to 20% over the same period (Table 4). Increases in FGK cover following overwintering were less pronounced in Run 2, which may be explained by the herbicide that was inadvertently applied to the site in May 2023, as growth regulator herbicides can suppress and injure *Cyperus* spp. (Pereira et al., 1987). Swollen FGK meristems and leaf necrosis were observed in the weeks following the application. Lower air temperatures may have also contributed, as monthly mean average temperatures for May 2023 in Run 2 were 2.2˚C cooler than in Run 1 in May 2022 (National Weather Service, 2024; Figure S1). Average temperatures for June and July 2023 in Run 2 were 1.2˚C and 1.1˚C cooler than in Run 1, respectively (National Weather Service, 2024; Figure S1).

In both low and high input programs seeded at 500 kg ha^{-1}, FGK cover was less than smooth crabgrass during the establishment year, but in the year after establishment, FGK and smooth crabgrass cover were similar due to FGK cover increasing substantially (Table 4). In July of the establishment year (Run 1, 2021), plots seeded with 500 kg ha-1 FGK had 73 and 8% cover in the low and high input plots, respectively. By the following July (Run 1, 2022), after overwintering, cover had increased to 90% and 47%, respectively. Similarly, when comparing seeded versus vegetative green kyllinga establishment, Lowe et al. (2000) found that green kyllinga cover was much lower when established from seed compared to shoots during the year of establishment, but cover differences due to establishment method were less prominent during the summer after overwintering (Lowe et al., 2000). In our research, although FGK cover remained lower in high input plots, the difference between input programs narrowed in the year after establishment, likely due to the perennial nature of FGK enabling continued spread once established.

3.6 | Turfgrass quality

Turfgrass input program affected turfgrass quality at every rating date (Table 5). The high input program improved turfgrass quality on every rating date compared to the low input program. When FGK and smooth crabgrass seedlings first emerged in May, the turfgrass quality in the high input plots was 6.9, whereas in the low input plots, it was 4.6. As the growing season progressed from July onward, weed cover began to increase and is attributed to reduced turfgrass quality. Smooth crabgrass established faster than FGK and contributed to reductions in turfgrass quality from July onward. In July of the establishment year, turfgrass quality in smooth crabgrass plots (3.8) was lower than in FGK plots (>6). Smooth crabgrass resulted in a turfgrass quality rating of 3.2 in August, whereas the 5 and 500 kg ha^{-1} rate of FGK

produced qualities of 6.7 and 5.8, respectively. FGK seeding rate affected turfgrass quality from August onward, as FGK seeded at 5 kg ha^{-1} resulted in greater turfgrass quality, except in September, where FGK seeding rate had no effect on quality. Following September ratings, turf quality declined more rapidly in FGK plots seeded at a 500 kg ha^{-1} rate compared to 5 kg ha^{-1} in October and November as the higher proportion of the C_4 FGK entered winter dormancy following frost events and the C_3 Kentucky bluegrass quality remained high into November.

4 | CONCLUSIONS

The objective of this experiment was to evaluate FGK establishment from seed compared to smooth crabgrass in turfgrass subjected to low and high input regimens designed to produce turfgrass swards of varying density. FGK can establish from seed in low and high-input turfgrass. However, high inputs to create a dense stand of turf reduced initial establishment of FGK from seed but had minimal effects on smooth crabgrass establishment. This suggests FGK is less competitive from seed than smooth crabgrass. FGK established when seeded at 5 kg ha^{-1}, suggesting it can establish via seed spread naturally or on practitioner equipment. Maintaining healthy and dense turfgrass can reduce but not eliminate initial establishment of FGK from seed. FGK seedlings are relatively benign in the establishment year, especially in dense turfgrass. Minor infestations expanded rapidly after overwintering, likely via rhizomes and possibly seed production. Future research should evaluate preemergence herbicides to control FGK from seed in cool-season turfgrass. Other research could investigate cultural practices such as mowing height or turfgrass species in combination with herbicide programs to manage FGK populations.

AUTHOR CONTRIBUTIONS

Trevor S. Watson: Conceptualization; data curation; formal analysis; investigation; methodology; visualization; writing—original draft; writing—review and editing. **Matthew T. Elmore**: Conceptualization; data curation; formal analysis; funding acquisition; methodology; resources; supervision; validation; writing—review and editing. **Aaron J. Patton**: Methodology; supervision; writing—review and editing. **Daniel P. Tuck**: Investigation; methodology; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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