HORTSCIENCE 54(10):1853–1859. 2019. https://doi.org/10.21273/HORTSCI14259-19

Flowering Persistence and Pollinator Attraction of Early-spring Bulbs in Warm-season Lawns

Michelle M. Wisdom, Michael D. Richardson, and Douglas E. Karcher
Department of Horticulture, University of Arkansas, 316 Plant Science Building, Fayetteville, AR 72701

Donald C. Steinkraus
Department of Entomology, University of Arkansas, 319 Agriculture Building, Fayetteville, AR 72701

Garry V. McDonald
Department of Horticulture, University of Arkansas, 316 Plant Science Building, Fayetteville, AR 72701

Additional index words. bermudagrass, buffalograss, *Buchloe dactyloides*, crocus, *Cynodon dactylon*, daffodil, grape hyacinth, pollinators, turfgrass

***Abstract*. Early-spring flowering bulbs can increase biodiversity while adding color to lawns and other grassy areas. However, few studies have investigated whether bulbs can flower and persist in warm-season lawns or provide feeding habitat for pollinating insects. Thirty early-spring flowering bulbs, including species of *Anemone*, *Chionodoxa*, *Crocus*, *Eranthis*, *Hyacinthus*, *Ipheion*, *Iris*, *Leucojum*, *Muscari*, and *Narcissus*, were established in bermudagrass (*Cynodon dactylon* L. Pers) and buffalograss [*Buchloe dactyloides* (Nutt.) J.T. Columbus] lawns in late autumn 2015 in Fayetteville AR. Bulbs were assessed over three growing seasons for flowering characteristics, persistence, and their ability to attract pollinating insects. A growing degree day model was also developed to predict peak flowering times in our region. Numerous bulb entries produced abundant flowers in bermudagrass and buffalograss lawns in the first year after planting, but persistence and flower production were reduced in both the second and third years of the trial. Five bulbs persisted for multiple years in both turfgrass species and continued to produce flowers, including *Crocus flavus* Weston 'Golden Yellow' (crocus), *Leucojum aestivum* L. (spring snowflake), *Narcissus* (daffodil) 'Baby Moon', *Narcissus* 'Rip Van Winkle', and *Narcissus* 'Tete-a-Tete'. Several bulbs, primarily crocuses and *Muscari* spp. (grape hyacinth), were also observed to attract pollinating insects, principally honey bees (*Apis mellifera*). These results demonstrate that some early-spring bulbs can persist in competitive warm-season turfgrasses, while providing pollinator forage, but species and cultivar selection is critical for long-term success.**

Flowering bulbs are known to naturalize in grassy areas like meadows and pastures (Bryan, 2002; Leeds, 2000). Although many plant species are described as bulbs or geophytes, their storage structures may be botanically characterized as corms, rhizomes, or tubers (Hessayon, 1996). Examples of true bulbs include *Hyacinthus* (hyacinth), *Muscari* (grape hyacinth), and *Narcissus* (daffodil) spp. (De Hertogh and Le Nard, 1993). *Crocus* (crocus) and *Gladiolus* (gladiola) spp. produce corms, and tubers and rhizomes are found in *Anemone* (windflower) and *Eranthis* (winter aconite) spp. (De Hertogh and Le Nard, 1993). To simplify this discussion here, the term "bulb" will be used to discuss all of these plants, including those with true bulbs, corms, tubers, and rhizomes.

Bulbs that naturalize in grassy areas must be vigorous enough to compete with the grass, and grass systems must be managed in a way to not damage the bulbs (i.e., postponing mowing or grazing until foliage has had time to senesce) (Hessayon, 1996). More than 16 million hectares of managed turfgrass are cultivated in the United States and represent lawns, golf courses, parks, roadsides, cemeteries, and athletic playing fields (Milesi et al., 2005). Both temperate (cool-season) and tropical (warm-season) grasses are used in turf situations and they vary considerably in their growth phases, with cool-season grasses growing most in spring and fall and warm-season grasses experiencing peak growth in the summer.

In the transition zone, warm-season turfgrasses can experience low-temperature induced dormancy for up to 6 months of the year (Patton, 2012). Two previous studies (Mirabile et al., 2016; Richardson et al., 2015) demonstrated that some flowering bulbs can persist in zoysiagrass (*Zoysia japonica* Steud.) and bermudagrass (*Cynodon dactylon*) in transition zone environments, providing color and biodiversity to dormant turfgrass situations. However, both studies examined a small number of bulb entries, and neither study documented how these plants might affect other organisms in the system, such as beneficial pollinating insects. In highly managed turfgrass systems, many flowering bulbs may be unable to withstand basic lawn cultural practices such as mowing or weed control.

Pollinator decline has been widely documented in recent years and has been associated with habitat and biodiversity loss, wide-spread planting of monocultures, pesticide usage, pollinator pests and diseases, and climate change (Biesmeijer et al., 2006; Goulson et al., 2015; Potts et al., 2010). Pollinator health is enhanced when diverse floral resources are available throughout the seasons when pollinators are active (Abrol, 2011; Goulson et al., 2015; Wackers and van Rijn, 2012). Significant expanses of managed turfgrasses, such as roadsides, cemeteries, and lawns, represent land areas that might be designed and managed to support pollinating insects (Hopwood, 2008; Ries et al., 2001). Historically, seed mixtures for lawns and pastures contained clover and other legumes (Tyson, 1941), which were included to provide nitrogen to the grass plants through symbiotic nitrogen fixation (Sincik and Acikgoz, 2007). However, a secondary benefit of those species was the abundant floral habitat provided to pollinating insects (Larson et al., 2014). With the advancement of the synthetic herbicide and fertilizer industry, flowering plants are often eliminated from turfgrass systems, consequently removing floral resources for pollinators.

Some flowering bulbs, such as crocus and grape hyacinth, have been documented to provide forage resources for honey bees in early spring (Steinkraus, 2010), but information on pollinator preference over a wide range of bulbs is limited. Identifying bulb species that could both add color to dormant warm-season turfgrasses and supply nutrition to pollinators, could fill two roles in many turfgrass ecosystems. If bulbs do not interfere with the majority of turfgrass cultural practices, they could provide additional ecosystem services of lawns and encourage home and business owners to establish pollinator-friendly habitats. The objectives of the current study were to investigate a large number of early-spring flowering bulbs for persistence in warm-season turfgrasses and determine if flowers produced by early-spring bulbs provide appropriate pollen and nectar resources for pollinating insects.

Materials and Methods

Three field studies were established in Nov. 2015 at the University of Arkansas Agricultural Research and Extension Center located in Fayetteville, AR (lat. 36°05′46.8″N, long. 94°10′28.5″W NAD83, 394 m

Received for publication 4 June 2019. Accepted for publication 31 July 2019.
We gratefully acknowledge the technical assistance provided by Paige Boyle, John McCalla, Daniel O'Brien, and Dan Sandor.
M.D.R. is the corresponding author. E-mail: mricha@uark.edu.

NAVD88). The soil at the site was a Captina silt loam (fine-silty, siliceous, active, mesic Typic Fragiudults) with an average pH of 6.2. Bulbs were incorporated into three distinct full-sun areas: a site established in 2005 to 'Riviera' bermudagrass, a site established in 2010 to 'Cody' buffalograss, and a raised bed where the native Captina silt loam soil had been amended several times over a 5-year period with local compost and covered by pine bark mulch, simulating a typical landscape planting bed. The sites were chosen to test differences in competitive habitats for the bulbs because bermudagrass is considered a dense, aggressive turfgrass, whereas buffalograss is considered a slower-growing, less aggressive native turfgrass (Christians et al., 2017). The raised bed was included to test and establish the overall viability of the bulb entries in the local climate with no competition from the turfgrass. Results from the raised bed have been reported elsewhere (Wisdom, 2018) and are not presented here; however, a few observations from that site are noted.

Mowing height of the bermudagrass and buffalograss areas was 7.5 cm and areas were mowed with a rotary mower every other week during the growing season with clippings returned. Mowing was initiated the second week of May each year, after the turfgrass fully recovered from dormancy. Although it is recognized that timing of mowing initiation would likely impact the persistence of bulb species differently, the date was chosen to represent when mowing would be typically initiated in the region. The turf areas were fertilized with 7.5 g N/m^2 (46N–0P–0K, Thrive Branded Urea; Mears Fertilizer, Inc., El Dorado, KS) in July of each year. In the absence of rainfall, plots were irrigated during the summer months to supply 2.0 cm water per week to prevent dormancy.

Bulbs were chosen based on the reported, mature height at bloom of less than 15 cm and a bloom period that would be completed by April or early May before mowing was resumed. The height parameter was included to minimize the weedy appearance of the bulbs in the turf and possibly allow mowing to occur earlier without removing a significant amount of leaf material. Thirty bulb entries were tested in this trial (Table 1) and all bulbs were purchased from one of three distributors (Brent and Becky's Bulbs, Glouchester, VA; McClure & Zimmerman, Randolph, WI; and Van Engelen Inc., Bantam, CT).

Bulbs were established in a randomized complete block design within each trial site. Plots established in the turfgrass sites measured 0.9 × 1.5 m, with 3 replications per bulb treatment and 25 bulbs per replicate. Although the total plot area for each treatment was 1.35 m^2, the bulbs were planted in a 0.9- × 0.9-m area in the center of the plot to accommodate for potential spread of bulbs. Plot size in the raised bed was 0.6 × 0.6 m, with 3 replicates per bulb entry and 25 bulbs per replicate. Holes were dug either using a hand trowel or with the aid of an auger attached to a cordless drill, depending on the bulb size. Each bulb was planted to a depth that was approximately twice its length and covered with loose native soil. *Crocus tommasinianus* Herb. 'Ruby Giant' demonstrated persistence in zoysiagrass at this location in a previous trial and was included as a positive control (Richardson et al., 2015).

Table 1. Bulb entries tested in a bermudagrass and buffalograss lawn, including species, cultivar (if known), and common name.

Scientific name	Cultivar (if known)	Common name
Anemone blanda Schott & Kotschy	Blue Shades	Windflower, thimbleweed
Anemone blanda	Pink Star	Windflower, thimbleweed
Chionodoxa forbesii Baker	Pink Giant	Glory of the snow
Chionodoxa sardensis Whittall ex Barr and Sugden		Glory of the snow
Crocus chrysanthus (Herb.) Herb.	Blue Pearl	Crocus
Crocus chrysanthus	Cream Beauty	Crocus
Crocus flavus Weston	Golden Yellow	Crocus
Crocus isauricus Siehe ex Bowles	Spring Beauty	Crocus
Crocus olivieri J. Gay subsp. *balansae*	Zwanenburg	Crocus
Crocus sieberi J. Gay	Tricolor	Crocus
Crocus tommasinianus Herb.	Ruby Giant	Crocus
Crocus vernus (L.) Hill	Remembrance	Crocus
Crocus vernus	Flower Record	Crocus
Eranthis hyemalis (L.) Salisb.		Winter aconite
Hyacinthus orientalis L.	Pink Pearl	Hyacinth
Ipheion uniflorum (Graham) Raf.		Spring starflower
Ipheion uniflorum	Rolf Fiedler	Spring starflower
Iris danfordiae (Baker) Boiss.		Iris
Iris histrioides (G.F. Wilson) S. Arn.	Katherine Hodgkin	Iris
Leucojum aestivum L.		Spring snowflake
Muscari	Valerie Finnis	Grape hyacinth
Muscari armeniacum Leichtlin ex Baker		Grape hyacinth
Muscari aucheri (Boiss.) Baker	Mount Hood	Grape hyacinth
Muscari neglectum Ten.		Grape hyacinth
Narcissus	Rijnveld's Early Sensation	Daffodil
Narcissus	Rip Van Winkle	Daffodil
Narcissus	Tete-a-Tete	Daffodil
Narcissus	Baby Moon	Daffodil
Narcissus canaliculatus Guss.		Daffodil
Narcissus jonquilla simplex L.		Daffodil

Data collection was primarily focused on performance and persistence of bulbs over a 3-year period (2016–18). Each treatment was evaluated for peak flower date and flowering abundance (% of bulbs with flowers). For the purposes of this work, satisfactory persistence was defined as >40% bulbs with flowers after three growing seasons, and nonpersistence was defined as <10% bulbs with flowers after three growing seasons. Data collection consisted of weekly counts of flower emergence and pollinator activity (if present).

To assess pollinator activity, each plot of 25 bulbs was visually inspected for pollinators on flowers, and the presence or absence of pollinator activity was noted. When assessing pollinator activity, only pollinators that visited a flower were counted; pollinators that were not observed on a flower were not counted. Pollinators were identified as members of Hymenoptera (honey bees, bumble bees, wasps, ants), Lepidoptera (butterflies), Diptera (flies), and Coleoptera (beetles).

Peak flower of each entry was modeled against accumulated growing degree days (GDD) using the following equation based on maximum daily air temperature ($TEMP_{max}$) and minimum daily air temperature ($TEMP_{min}$) data collected using an onsite weather station:

$$GDD = (TEMP_{max} + TEMP_{min}) / 2 - Base\ temperature\ (0°\ C)$$

The base temperature in the growing degree day equation was assigned 0 °C to represent bulb dormancy and the accumulation of GDD units was initiated on 1 Jan. during each year of the trial. Although limited information is available regarding the temperature at which growth is initiated in early spring bulbs, the temperatures used to chill and suspend growth of species such as daffodils, crocus, and grape hyacinth are in the range of 5 to 8 °C (De Hertogh and Le Nard, 1993). As such, it was anticipated that no growth would occur for any of the entries at air temperatures of 0 °C or less. Regression analysis was used to determine if GDD units accumulated to peak flower periods were good predictors of that parameter in subsequent years of the trial. Because the flowering data from 2016 represented an establishment year and may not be indicative of long-term flowering patterns, the regression analysis compared the peak flower periods of the second (2017) and third (2018) years of the trial.

The three planting sites were not replicated and were analyzed separately by an analysis of variance (ANOVA), with mean separation tests performed using Fisher's protected least significant difference (P = 0.05). ANOVA (data not shown) indicated a significant effect of year and entry on peak flowering date and number of blooms with flowers for each site. In addition, there was a significant year × entry interaction on each of those parameters. As such, all data were analyzed by site and year and data are presented to show the effects of entry within year for each site.

Results and Discussion

Bulb performance in a bermudagrass lawn. During the trial, peak flower emergence occurred over a 3-month period from mid-February through early May each season (Table 2). *Iris danfordiae* (Baker) Boiss. and several crocus entries were the first bulbs to produce flowers each year, whereas daffodil and grape hyacinths flowered last (Table 2). Overall, 20 of the 30 bulb entries produced peak flowers during late February or early March in Fayetteville, AR.

In 2016, five species (Crocus 'Blue Pearl', 'Cream Beauty', and 'Golden Yellow', Hyacinth 'Pink Pearl', and Narcissus 'Rip Van Winkle') produced flowers on more than 90% of the bulbs planted (Table2). However, in 2017 and 2018, flower production decreased for all species, and none of the entries had >90% bulbs with flowers. In the second year of the trial, only entries of crocus, spring snowflake, and daffodil showed >50% flowering in bermudagrass (Table 2). The entries that showed the best persistence after three seasons in bermudagrass included the crocuses ('Golden Yellow', 'Ruby Giant', and 'Flower Record'), the spring snowflake, and several daffodil entries ('Baby Moon', 'Rip Van Winkle', and 'Tete-a-Tete'). Several entries, including *Hyacinthus orientalis* L. 'Pink Pearl', *Muscari aucheri* (Boiss.) Baker 'Mount Hood', and *Muscari neglectum* Ten. produced abundant flowers (>70%) in 2016 (Table 3), but they produced minimal flowers (<20%) in 2017 or 2018 (Table 4). Many early-spring flowering bulbs did not persist in bermudagrass, including windflower, glory of the snow, winter aconite, iris, hyacinth, and grape hyacinth 'Valarie Finnis' (<10% bulbs with flowers after 3 years) (Table 2).

Bulb performance in a buffalograss lawn. Similar to the bermudagrass site, peak flower emergence occurred over a 3-month period from early February through May (Table 3). Although there were subtle differences between the sites each year, there was no evidence that bulbs flowered at different time periods in the bermudagrass and buffalograss lawns. During the first year after planting (2016), several entries produced flowers on >90% of the planted bulbs, including the grape hyacinths 'Mount Hood' and 'Valerie Finnis' and several daffodil entries (Table 3). However, after 3 years, only the daffodil 'Baby Moon' produced flowers on >90% of the established bulbs (Table 3). It is worth noting that nine entries in buffalograss had >40% bulbs with flowers after 3 years compared with only six entries in bermudagrass during the same period (Table 2). This suggested that the less competitive buffalograss was a more favorable environment for the spring bulbs, but we were unable to statistically compare those treatments across sites. Several of the bulbs also performed poorly over the 3 years in buffalograss. In the third season, windflower, winter aconite, iris, and some entries of crocus and daffodil had ceased flowering (Table 3). Overall, daffodils, crocus, and grape hyacinths demonstrated the greatest propensity to persist and flower in a buffalograss lawn.

Bulb performance in a raised bed. Performance data of bulbs in the raised bed have been presented in detail previously (Wisdom, 2018), but several observations should be noted here. Six bulb entries failed to persist in the raised bed site over 3 years, including the crocus entries 'Zwanenburg' and 'Tricolor', winter aconite, iris, and hyacinth (Wisdom, 2018). Entries that failed in both turfgrass sites included windflower (*Anemone blanda* Schott & Kotschy), winter aconite [*Eranthis hyemalis* (L.) Salisb.], *Iris danfordiae* (iris), and *Muscari neglectum* (grape hyacinth). Two of these entries, winter aconite and *Iris danfordiae*, also failed in the raised bed, suggesting that they were not adaptable in the northwest region of Arkansas. The windflower 'Pink Star' and the grape hyacinth *Muscari neglectum* persisted in the raised bed, but they were unable to sustain flowering in the more competitive turfgrass environments.

Table 2. Effects of various spring bulb entries on day of year (DOY) of peak flower and percentage of 25 planted bulbs that produced flowers in a bermudagrass lawn. Entries are sorted from highest to lowest bulb flowering in year 3 (2018) of the trial.

		Peak flower date (DOY)			Planted bulbs that produced flowers (%)		
Scientific name	Cultivar (if known)	2016	2017	2018	2016	2017	2018
Narcissus spp.	Baby Moon	69.0	60.7	66.0	89.3	38.7	89.3
Crocus flavus	Golden Yellow	54.3	45.0	51.0	98.7	57.3	65.3
Crocus tommasinianus	Ruby Giant	69.0	68.0	66.0	40.0	49.3	57.3
Crocus vernus	Flower Record	69.0	52.3	66.0	37.3	28.0	49.3
Leucojum aestivum		83.0	92.0	102.0	88.0	80.0	46.7
Narcissus spp.	Rijnveld's Early Sensation	102.0	68.0	122.0	84.0	66.7	40.0
Crocus vernus	Remembrance	59.5	50.0	66.0	24.0	48.0	38.7
Muscari aucheri	Mount Hood	83.0	82.0	99.7	97.3	20.0	28.0
Crocus isauricus	Spring Beauty	63.0	50.0	60.0	46.7	29.3	24.0
Muscari armeniacum		83.0	84.7	101.7	94.7	30.7	18.7
Crocus chrysanthus	Blue Pearl	54.3	45.0	51.3	96.0	36.0	17.3
Muscari neglectum		80.3	55.5	97.3	88.0	1.8	17.3
Chionodoxa sardensis		77.7	69.0	69.0	32.0	9.3	14.7
Narcissus spp.	Tete-a-Tete	102.0	96.0	102.0	34.7	85.3	13.3
Crocus chrysanthus	Cream Beauty	54.3	56.0	54.3	96.0	21.3	10.7
Crocus sieberi	Tricolor	54.3	52.3	57.0	68.0	24.0	4.0
Iris histrioides	Katherine Hodgkin	53.0	49.0	58.5	88.0	33.3	2.7
Muscari spp.	Valerie Finnis	75.0	90.0	80.5	80.0	26.7	2.7
Ipheion uniflorum	Rolf Fiedler	111.0	82.0	102.0	4.0	17.3	1.3
Anemone blanda	Blue Shades	89.3	—	—	24.0	0.0	0.0
Anemone blanda	Pink Star	83.0	—	—	2.7	0.0	0.0
Chionodoxa forbesii	Pink Giant	75.0	68.0	—	16.0	1.3	0.0
Crocus olivieri balansae	Zwanenburg	58.7	41.0	—	36.0	4.0	0.0
Eranthis hyemalis		83.0	—	—	6.7	0.0	0.0
Hyacinthus orientalis	Pink Pearl	75.0	50.0	—	98.7	1.3	0.0
Ipheion uniflorum		83.0	90.0	—	4.0	13.3	0.0
Iris danfordiae		48.3	50.0	—	41.3	1.3	0.0
Narcissus canaliculatus		69.0	54.7	—	86.7	32.0	0.0
Narcissus jonquilla simplex		75.0	84.7	—	97.3	26.7	0.0
Narcissus spp.	Rip Van Winkle	75.0	57.0	—	54.7	89.3	0.0
	LSD[z] (0.05)	6.4	7.6	9.9	22.6	26.1	26.8

[z]LSD = Fisher's protected least significant difference ($\alpha = 0.05$) values for determining whether means within a column are significantly different.

Table 3. Effects of various spring bulb entries on day of year (DOY) of peak flower and percentage of 25 planted bulbs that produced flowers in a buffalograss lawn. Entries are sorted from highest to lowest bulb flowering in year 3 (2018) of the trial.

		Peak flower date (DOY)			Planted bulbs that produced flowers (%)		
Scientific name	Cultivar (if known)	2016	2017	2018	2016	2017	2018
Narcissus spp.	Baby Moon	72.0	98.3	66.0	98.7	96.0	100.0
Crocus flavus	Golden Yellow	55.0	45.0	49.3	80.0	85.3	77.3
Narcissus spp.	Rijnveld's Early Sensation	102.0	60.7	122.0	48.0	52.0	72.0
Muscari aucheri	Mount Hood	83.0	75.0	99.7	92.0	77.3	69.3
Crocus chrysanthus	Cream Beauty	54.0	42.3	47.7	86.7	81.3	66.7
Leucojum aestivum		83.0	90.0	102.0	80.0	85.3	57.3
Muscari neglectum		72.0	59.7	97.3	86.7	11.8	54.7
Crocus tommasinianus	Ruby Giant	72.0	68.0	66.0	40.0	53.3	46.7
Muscari armeniacum		83.0	82.0	108.7	74.7	84.0	41.3
Crocus isauricus	Spring Beauty	60.3	45.0	53.0	29.3	49.3	38.7
Crocus chrysanthus	Blue Pearl	54.0	45.0	49.3	84.0	74.7	22.7
Ipheion uniflorum	Rolf Fiedler	92.5	75.0	99.7	5.3	26.7	21.3
Crocus vernus	Flower Record	72.0	60.7	70.5	53.3	25.3	10.7
Crocus vernus	Remembrance	72.0	64.3	66.0	28.0	26.7	9.3
Hyacinthus orientalis	Pink Pearl	72.0	56.0	72.0	86.7	33.3	9.3
Chionodoxa forbesii	Pink Giant	72.0	68.0	69.0	57.3	17.3	8.0
Iris histrioides	Katherine Hodgkin	53.0	46.7	70.5	74.7	42.7	8.0
Chionodoxa sardensis		83.0	72.7	75.0	46.7	14.7	6.7
Crocus olivieri balansae	Zwanenburg	55.0	32.3	46.0	80.0	41.3	5.3
Ipheion uniflorum		83.0	84.7	112.0	2.7	33.3	4.0
Narcissus spp.	Tete-a-Tete	102.0	57.0	102.0	58.7	97.3	4.0
Eranthis hyemalis		65.7	45.0	66.0	9.3	8.0	2.7
Muscari spp.	Valerie Finnis	79.3	92.0	75.0	90.7	48.0	2.7
Narcissus canaliculatus		72.0	60.7	75.0	93.3	57.3	1.3
Anemone blanda	Blue Shades	83.0	75.0	—	45.3	12.0	0.0
Anemone blanda	Pink Star	83.0	75.0	—	5.3	1.3	0.0
Crocus sieberi	Tricolor	56.0	45.0	—	49.3	44.0	0.0
Iris danfordiae		53.0	45.0	—	34.7	8.0	0.0
Narcissus jonquilla simplex		75.7	90.0	—	100.0	24.0	0.0
Narcissus spp.	Rip Van Winkle	83.0	68.0	—	74.7	76.0	0.0
	LSD[z] (0.05)	6.2	7.6	7.5	16.8	23.7	18.6

[z]LSD = Fisher's protected least significant difference ($\alpha = 0.05$) values for determining whether means within a column are significantly different.

Table 4. Growing degree day (GDD) units required for peak flowering of 30 early-spring bulbs established in a bermudagrass and buffalograss lawn. Entries are sorted from lowest to highest 2-yr average GDD units for peak flower on the buffalograss site.

		Bermudagrass			Buffalograss		
		2017	2018	2-yr avg	2017	2018	2-yr avg
Scientific name	Cultivar (if known)	GDD units for peak flower[z]					
Crocus olivieri balansae	Zwanenburg	286	nd	286	213	191	202
Crocus chrysanthus	Blue Pearl	323	241	282	298	230	264
Crocus chrysanthus	Cream Beauty	456	255	356	323	207	265
Crocus flavus	Golden Yellow	323	241	282	323	230	277
Crocus isauricus	Spring Beauty	396	316	356	323	247	285
Crocus sieberi	Tricolor	422	281	352	323	nd	323
Iris danfordiae		396	nd	396	323	nd	323
Eranthis hyemalis		nd	nd	nd	323	369	346
Iris histrioides	Katherine Hodgkin	374	291	332	347	416	382
Narcissus spp.	Tete-a-Tete	475	369	422	475	369	422
Crocus vernus	Flower Record	422	369	396	509	369	439
Hyacinthus orientalis	Pink Pearl	396	nd	396	456	421	439
Crocus tommasinianus	Ruby Giant	577	369	473	576	369	473
Crocus vernus	Remembrance	396	369	383	542	412	477
Narcissus spp.	Rijnveld's Early Sensation	509	nd	509	509	465	487
Chionodoxa forbesii	Pink Giant	577	nd	577	576	404	490
Muscari neglectum		553	517	535	553	465	509
Narcissus canaliculatus		449	nd	449	509	nd	509
Chionodoxa sardensis		594	404	499	597	464	531
Narcissus spp.	Rip Van Winkle	577	nd	577	576	nd	576
Anemone blanda	Pink Star	nd	nd	nd	608	nd	608
Anemone blanda	Blue Shades	nd	nd	nd	653	nd	653
Muscari aucheri	Mount Hood	729	701	715	608	701	655
Ipheion uniflorum		839	759	799	638	718	678
Muscari armeniacum		766	718	742	729	718	724
Leucojum aestivum		870	759	815	839	759	799
Narcissus jonquilla simplex		766	759	762	839	759	799
Ipheion uniflorum	Rolf Fiedler	729	nd	729	766	877	821
Muscari spp.	Valerie Finnis	839	759	799	870	841	856
Narcissus spp.	Baby Moon	933	1044	989	976	1044	1010

[z]Growing degree units were calculated using a base temperature of 0 °C and were accumulated beginning on 1 Jan. of each year.
nd = not determined.

Previous studies have shown that establishing early-spring flowering bulbs into areas of zoysiagrass and bermudagrass is an appropriate practice for those who desire color and biodiversity in a dormant lawn (Mirabile et al., 2016; Richardson et al., 2015). The daffodil 'Rip Van Winkle' was tested in both the present trial and the study by Mirabile et al. (2016), and it showed persistence over time in transition zones of the United States and Italy. Research trials performed at Cornell University in Ithaca, NY (planting zone 5a: –28.9 to –26.1 °C), the University of Kentucky in Lexington, KY (zone 5b: –26.1 to –23.3 °C), and Purdue University in West Lafayette, IN (zone 5b: –26.1 to –23.3 °C) demonstrated that several species of early-spring flowering bulbs, which were not suited to lawns in Arkansas (zone 6b, 7a: –20.6 to –15 °C) persisted and flourished in the cooler climates of New York, Kentucky, and Indiana, including windflower, hyacinth, spring starflower [*Ipheion uniflorum* (Graham) Raf.], glory-of-the-snow (*Chionodoxa forbesii* Baker), and winter aconite (Anderson, 2004; Cornell University, 2007; Dana, 2001). Each entry noted here had well below the 40% level of success in northwest Arkansas in the present study, suggesting that transition zone temperatures are too high or that the competitive conditions within the turfgrass environment limited successful bulb establishment. Nonetheless, across the two lawn sites, several of the better-adapted bulbs produced an excellent floral display in early-spring while the lawns remained dormant (Fig. 1) and would be considered a desirable addition to these and other low-maintenance turfgrass sites.

One final observation from these trials that is worth noting is that some of the entries tested had a mature height that exceeded the advertised height of 15 cm. This was especially evident with the daffodils, where several of the entries that persisted also produced an excessive amount of foliage (20–30 cm height). This was considered undesirable for lawn settings because the plants were much more evident in the lawns and might be viewed as weedy (Fig. 1D). Plant height and leaf characteristics of the crocus and grape hyacinth allow those bulb species to blend better with the existing lawn (Fig. 1A–C). In addition, an abundance of foliage remain unaffected, even after mowing at 7.5 cm is commenced, which should enhance persistence in the following season.

Growing degree day model. Regression analysis was used to determine if GDD estimates of peak flower in the second year of the trial were good predictors of that parameter in the subsequent year of the trial. As previously noted, the GDD equation base temperature was assigned 0 °C to ensure that all physiological activity within individual bulbs had ceased before beginning the accumulation of GDD units.

At this location, early-spring flowering bulbs needed 200 to 1000 accumulated GDD units from 1 Jan. to reach full flower in both the bermudagrass and buffalograss lawns (Table 4). In addition, a linear relationship ($P < 0.001$) was observed between the 2017 and 2018 GDD units when peak flowering occurred (Fig. 2). The linear model accounted for more than 80% of the variation in the data for both sites ($r^2 = 0.81$ and 0.82 for bermudagrass and buffalograss, respectively). Heat accumulation has a significant impact on the rate of development of crops and many other organisms (Payero, 2017), and temperature modification is commonly manipulated to force dormancy and flowering in ornamental bulbs (De Hertogh and Le Nard, 1993). Although the GDD units needed to reach peak flower were an adequate predictor of flowering in subsequent trial years, these data are limited to a single location, and flowering of spring bulbs is also known to be influenced by environmental factors such as soil moisture and soil type (De Hertogh and Le Nard, 1993) and the age of the bulbs. Additional research is needed to verify whether these models can accurately predict bulb flowering in other locations, and unfortunately, we are unaware of any previous GDD models that have been developed to predict flowering in early-spring bulbs. However, if more robust GDD models to predict flowering could be developed, they could be a useful decision-making tool for selecting flowering bulbs best suited to a particular planting location.

Fig. 1. Examples of early spring bulbs flowering in bermudagrass or buffalograss lawns. (**A**) Grape hyacinth (*Muscari armeniacum*), (**B**) crocus (*Crocus chrysanthus* 'Cream Beauty'), (**C**) crocus (*Crocus tommasinianus* 'Ruby Giant'), and (**D**) daffodil (*Narcissus* spp. 'Tete-a-Tete').

Pollinator activity on early-spring bulbs. Native bees and other pollinators are typically not active during late winter months, but honey bees will forage on mild winter days, although they may be limited by temperature to short distance flights (Hodges, 1952). Pollinator activity counts were only taken on warmer winter days (>10 °C) when some activity would be expected. All pollinators observed during these trials were classified as honey bees.

In bermudagrass, pollinator activity was exclusively observed on three species of grape hyacinth, including 'Valerie Finnis', *Muscari armeniacum* Leichtlin ex Baker, and 'Mount Hood' in 2016; in 2017, pollinators were also observed foraging on crocus ('Blue Pearl' and 'Golden Yellow') and spring starflower 'Rolf Fiedler' (data not shown). In buffalograss, pollinator activity was observed on three species of grape hyacinth, including 'Valerie Finnis', *Muscari armeniacum*, and *Muscari neglectum*, in 2016; in 2017, pollinators were observed on several crocus entries ('Blue Pearl', 'Cream Beauty', 'Golden Yellow', 'Spring Beauty', and 'Remembrance'), hyacinth 'Pink Pearl', spring starflower, and two entries of grape hyacinth (*Muscari armeniacum* and *Muscari aucheri* 'Mount Hood') (data not shown) (Fig. 3).

Although anecdotal observations of pollinator activity on cultivars of grape hyacinth and crocus are widely reported online, only limited scientific studies have documented these associations. Totland and Matthews (1998) observed that a range of pollinating insects visited wild populations of *Crocus vernus* (L.) Hill and they were nonselective in their foraging habits based on flower size and color. In the present study, honey bees were observed foraging on several of the crocus entries, including 'Golden Yellow', 'Blue Pearl', 'Cream Beauty', 'Spring Beauty', and 'Remembrance'. These entries exhibit a broad range of floral characteristics, from pale yellow to orange to deep purple; therefore, flower color had no apparent positive or

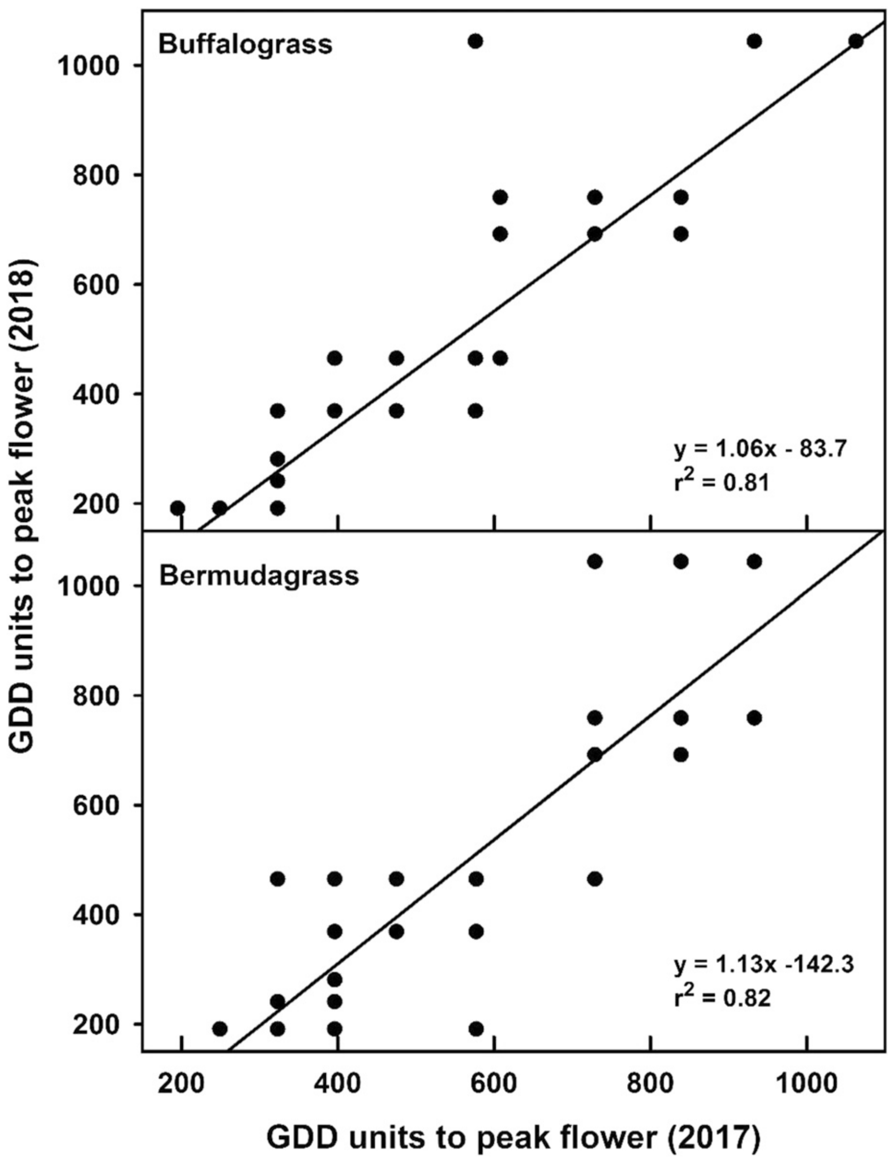

Fig. 2. Regression analysis comparing number of growing degree day units (base temperature = 0 °C) required for peak flower emergence in the second year (2017) compared to the third year (2018) of the trial in a bermudagrass and buffalograss lawn.

Fig. 3. Honey bees visiting early spring bulbs in a warm-season lawn, including (**A**) grape hyacinth (*Muscari aucheri* 'Mount Hood') and (**B**) crocus (*Crocus flavus* 'Golden Yellow').

negative effects on their attractiveness to honey bees. Carta et al. (2015) examined chemical profiles of four species of *Crocus* and identified several aromatic compounds in all species that are considered floral attractants to pollinating insects. Insect pollinators have also been categorized on wild species of *Muscari comosum* (L.) Mill. in northern Italy (Canale et al., 2014) and the authors suggested that *Muscari* could be a valuable early-season pollen source for foraging insects. In both the present study and other studies carried out at our facility, we have consistently seen honey bees foraging on grape hyacinth and would consider it an excellent pollinator source in early-spring landscapes.

Conclusions

Thirty flowering bulbs were tested over a 3-year period in bermudagrass and buffalograss in northwest Arkansas. This study demonstrated that several bulb species can persist in warm-season lawns and provide visual interest in early-season landscapes. In addition, several entries of crocus and grape hyacinth were foraged on by honey bees. As a group, the crocus and grape hyacinths were most successful at both persisting and providing a pollinator habitat. The benefit to pollinators confirms another potential ecosystem service of lawns in both urban and rural environments. Further research outside of the present geographic region is needed to establish a more comprehensive list of early-spring flowering bulbs for home or business owners interested in establishing color and/or pollinator forage sources in their lawn. Specifically, trial sites need to be expanded to other geographic regions, where varying dormancy periods of lawns and different adaptation and flowering periods of bulbs species could reveal unique combinations of lawns and bulbs that might also be sustainable. To date, there have been no studies which have tested the suitability and persistence of bulb species in cool-season lawns such as bluegrass (*Poa* spp.), fescue (*Festuca* spp.), or ryegrass (*Lolium* spp.), although work has recently been initiated in Virginia (Shawn Askew, Virginia Tech University, personal communication). Because cool-season grasses often do not undergo a dormancy period, they might be more competitive with bulbs during the flowering period and earlier mowing practices might also hinder persistence of the bulbs.

Literature Cited

Abrol, D.P. 2011. Pollination biology: Biodiversity conservation and agricultural production. Springer, New York, NY.

Anderson, R.G. 2004. Spring flowering bulbs for Kentucky gardens. Kent. Coop. Ext. Serv. Bul. HortFacts 52-04.

Biesmeijer, J.C., M. Edwards, R. Kleukers, W.E. Kunin, R. Ohlemuller, T. Peeters, S.G. Potts, M. Reemer, S.P.M. Roberts, A.P. Shaffers, J. Settele, and C.D. Thomas. 2006. Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. Science 313:351–354.

Bryan, J.E. 2002. Bulbs. Timber Press, Portland, OR.

Canale, A., G. Benelli, and S. Benvenuti. 2014. First record of insect pollinators visiting *Muscari comosum* (L.) Miller (Liliaceae-Hyacinthaceae), an ancient Mediterranean food plant. Plant Biosyst. 148:889–894.

Carta, A., G. Flamini, P.L. Cioni, L. Pistelli, and L. Peruzzi. 2015. Flower bouquet variation in four species of *Crocus* ser. *Verni*. J. Chem. Ecol. 41:105–110.

Christians, N.E., A.J. Patton, and Q.D. Law. 2017. Fundamentals of turfgrass management. 5th ed. Wiley, Hoboken, NJ.

Cornell University. 2007. Best 15 bulb & perennial combinations. Department of Horticulture, Ithaca. <http://www.hort.cornell.edu/combos/FeaturedCombos/Best15Combos/index.html>.

Dana, M.N. 2001. Flowering bulbs. Purd. Univ. Coop. Ext. Serv. HO-86-W.

De Hertogh, A.A. and M. Le Nard. 1993. Botanical aspects of flower bulbs, p. 7-20. In: De Hertogh and Le Nard (eds.). The physiology of flower bulbs. Elsevier, Amsterdam, Netherlands.

Goulson, D., E. Nicholls, C. Botias, and E.L. Rotheray. 2015. Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. Science 347(6229):1255957, doi: 10.1126/science.

Hessayon, D.G. 1996. The bulb expert. Transworld Publishers, London.

Hodges, D. 1952. The pollen loads of the honey bee: A guide to their identification by colour and form. Intl. Bee Res. Assn., London, England.

Hopwood, J.L. 2008. The contribution of roadside grassland restorations to native bee conservation. Biol. Conserv. 141:2632–2640.

Larson, J.L., A.J. Kesheimer, and D.A. Potter. 2014. Pollinator assemblages on dandelions and white clover in urban and suburban lawns. J. Insect Conserv. 18:863–873.

Leeds, R. 2000. The plantfinder's guide to early bulbs. ASHS Press, Alexandria, VA.

Milesi, C., S.W. Running, C.D. Elvidge, J.B. Dietz, B.T. Tuttle, and R.R. Nemani. 2005. Mapping and modeling the biogeochemical cycling of turf grasses in the United States. Environ. Manage. 36:426–438.

Mirabile, M., F. Bretzel, M. Gaetani, and F. Lulli. 2016. Improving aesthetic and diversity of bermudagrass lawn in its dormancy period. Urban For. Urban Green. 18:190–197.

Patton, A. 2012. Warming up in the transition zone. USGA Green Sect. Rec. 50:1–5.

Payero, J. 2017. Introduction to growing degree days. Clem. Coop. Ext. AC-09.

Potts, S.G., J.C. Biesmeijer, C. Kremen, P. Neumann, O. Schweiger, and W.E. Kunin. 2010. Global pollinator declines: Trends, impacts, and drivers. Trends Ecol. Evol. 25:345–353.

Richardson, M.D., J. McCalla, T. Buxton, and F. Lulli. 2015. Incorporating early spring bulbs into dormant warm-season turfgrasses. HortTechnology 25:228–232.

Ries, L., D.M. Debinski, and M.L. Wieland. 2001. Conservation value of roadside prairie restoration to butterfly communities. Conserv. Biol. 15:401–411.

Sincik, M. and E. Acikgoz. 2007. Effects of white clover inclusion on turf characteristics, nitrogen fixation, and nitrogen transfer from white clover to grass species in turf mixtures. Commun. Soil Sci. Plan. 38:1861–1877.

Steinkraus, D. 2010. Early spring flowers in Northwest Arkansas: The excellent, the good, and the poor. Amer. Bee J. 150:351–354.

Totland, Ø. and I. Matthews. 1998. Determination of pollinator activity and flower preference in the early spring blooming *Crocus vernus*. Acta Oecol. 19:155–165.

Tyson, J. 1941. Growing beautiful lawns. Mich. Agr. Expt. Sta. Res. Bul. 224.

Wackers, F.L. and P.C.J. van Rijn. 2012. Pick and mix: Selecting flowering plants to meet the requirements of target biological control insects, p. 139–165. In: G.M. Gurr, S.D. Wratten, W.E. Snyder, and D.M.Y. Read (eds.). Biodiversity and insect pests: Key issues for sustainable management. Wiley, Chichester, England.

Wisdom, M.M. 2018. Systems to attract and feed pollinators in warm-season lawns. Univ. of Arkansas, Fayetteville, MS Thesis. 2975. <https://scholarworks.uark.edu/etd/2975>.