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Systems to Attract and Feed Pollinators in Warm-Season Lawns

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Systems to Attract and Feed Pollinators in Warm-Season Lawns

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Abstract

Pollinating insects are responsible for the production of many agricultural crops and they require floral resources to fulfill their life-cycle. Ideally, pollinating insects will encounter a diversity of floral resources across their entire season of activity, and those floral resources can include both herbaceous and woody plant species. Managed turfgrass areas have been identified as potential locations for creating pollinator-friendly habitats. In the transition zone, where both warm- and cool-season turfgrass species are present, the persistence of herbaceous plants in warm-season turfgrasses such as bermudagrass (*Cynodon* spp.) and buffalograss (*Buchloe dactyloides*), may be affected not only by the competitive nature of the turfgrass, but by the cultural practices associated with turfgrass management. While exhibiting prolific growth throughout the growing season, warm-season turfgrasses experience an extended dormancy period from late fall to spring. Loss of green color during dormancy might be countered with a display of color from flowering bulbs. Many early-spring bulbs emerge, flower, and senesce before warm-season turfgrass breaks dormancy, and are potential sources for pollinator nutrition at a time when few nutritive resources are available. Additionally, many broadleaf perennial plants commonly found in lawns throughout the season may provide nutrition to pollinating insects during spring, summer, and fall months. A series of field trials were conducted in Arkansas over two years (2016-2017), testing 30 cultivars of early-spring flowering bulbs and eight flowering, broadleaf perennial plants (forbs) in warm-season lawns. The overall goal of the project were to identify bulbs and forbs which would persist in warm-season lawns and provide season-long floral resources for pollinating insects. Five species of flowering bulbs exhibited persistence in both bermudagrass and buffalograss lawns, with flowering times ranging from January-May. Several bulb species were also used as early-season food sources for pollinating insects. Five species of

forb also persisted in a bermudagrass lawn and provided pollinator forage in the spring, summer and fall months. In conclusion, a combination of early-spring flowering bulbs and flowering, broadleaf perennials can persist in warm-season turfgrasses and supply nutrition to pollinating insects. The benefit to pollinators confirms another potential ecosystem service of turfgrasses in both urban and rural environments.

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Literature Review

Pollinators

Pollination is simply the transfer of pollen from the stamen, or male portion of a flower, to the stigma, or female portion of a flower (Von Frische, 1954). Pollination occurs either abiotically (movement by wind or water) or biotically (movement by animal courier) (Ackerman, 2000; Allsopp et al., 2008). Examples of biological pollinators are bees, wasps, and ants (all members of Hymenoptera), flies (Diptera), butterflies and moths (Lepidoptera), beetles (Coleoptera), birds (Apodiformes), and mammals such as bats (Chiroptera) and lemurs (Primates) (Overdorff, 1992; Potts et al., 2016; Sussman and Raven, 1978). As these animals forage pollen and nectar from plants, they dislodge pollen and distribute it throughout their feeding range. The transfer of pollen initiates seed and fruit set in the plant, resulting in many of the fresh fruits, vegetables, nuts, oils, and stimulants (coffee and chocolate) we have grown accustomed to finding at the market any time of year. Eighty-seven of the top 115 global food crops require movement of pollen from one flower to another by animal vectors (Klein et al., 2006). In 2009, Gallai et al. put the total economic value of pollination worldwide at €153 billion ($178 billion US$ at current exchange rates). Pollinated crops include apple (*Malus domestica*), almond (*Prunus dulcis*), avocado (*Persea americana*), blueberry (*Vaccinium* spp.), cinnamon (*Cinnamomum verum*), eggplant (*Solanum melongena*), melon (*Cucumis* spp.), peach (*Prunus persica*), pumpkin (*Curcurbita pepo*), and strawberry (*Fragaria* spp.) (University of Arkansas Division of Agriculture, 2017). Livestock forages such as alfalfa (*Medicago sativa*), buckwheat (*Fagopyrum esculentum*) and clover (*Trifolium* spp.) also depend upon insect pollinators to produce a seed crop. Not only do many human sustenance crops require pollination, it is estimated that 87.5% of all flowering plants (angiosperms) depend upon some form of biotic pollination (Ollerton et al., 2011). Fittingly, the plant/pollinator relationship is mutually beneficial, as plants supply nourishment, in the form of pollen and nectar, to the animal, while the animal ensures reproduction and survival in plants via seed and fruit set. With insects, especially bees, it is important to understand that pollen provides the essential proteins, lipids, vitamins, and minerals that are required for healthy larval development and adult function (Scofield and Mattila, 2015).

Bees, including honey bees, bumble bees, and solitary bees, are the most prominent and economically important group of pollinators worldwide (Klein et al., 2006; Potts et al., 2016). Currently, much of the public interest in pollinators is centered on *Apis mellifera*, the European honey bee, a non-native species introduced to the US by settlers hundreds of years ago (Texas A & M University, 2006). Honey bees alone are responsible for pollinating over 100 horticultural crops in the United States (University of Arkansas Division of Agriculture, 2017). The honey bee is managed for both honey production and pollination services (Morse and Calderone, 2000) and is the single most important crop pollinator (McGregor, 1976). It is estimated that honey bee pollination services add $15 billion annually to the US economy (Office of the Press Secretary, 2014). In fact, yields of some fruit, seed and nut crops decline by more than 90% without these pollinators (Southwick and Southwick, 1992). Honey bees reside in social, densely-populated communities of up to 60,000 individuals. Each colony has a clear hierarchy, beginning with the reproductive female, or queen. Each bee has a role within that hierarchy, with a division of labor amongst the individuals, cooperative brood care, and overlapping generations within the colony (Von Frische, 1954). Colonies can be easily managed by beekeepers as hives are relatively lightweight and mobile. In commercial situations, hives can be transported long distances to provide pollination services to large acreages of assorted cropping systems, and/or monocultures such as almond orchards in California (Glenny et al., 2017). Although the honey bee is the main focus in pollination services, studies have shown that visits by wild pollinators increased fruit set even where substantial quantities of managed bees were present, suggesting that the pollination contribution of wild bees is unique and additive to that of managed bees (Carvalheiro et al., 2010; Mallinger and Gratton, 2014).

There are over 4000 native bee species in the United States (Moisset and Buchman, 2011). Notably, wild, unmanaged bees add roughly $9 billion annually to the US economy through their pollination services (Office of the Press Secretary, 2014). For many crops, wild bees are also better pollinators compared to honey bees (Garibaldi et al., 2013). Wild pollinators fulfill many roles, including directly pollinating crops for human consumption, and providing pollination for seed production in forage legumes such as alfalfa (United States Department of Agriculture, 2009). Wild bees include bumble bees (*Bombus* spp.), mason bees (*Osmia* spp.), leafcutter bees (*Megachile* spp.), carpenter bees (*Xylocopa* spp.), sweat bees (*Halictidae* spp.), squash bees (*Peponapis* spp.; *Xenoglossa* spp.), and cuckoo bees (*Thyreus* spp.). Many wild, native bees are solitary creatures. They do not have a queen, produce honey, or live in colonies. They dwell in diverse locations such as cavities underground, hollow-stemmed twigs, burrows in the soil, or even abandoned snail shells (Goulson et al., 2015; Shepherd et al., 2003). Bumble bees are an exception, and are recognized as a primitive eusocial group (Del Castillo et al., 2015; Goulson, 2003). They reside in colonies of up to 500 individuals, but are less rigidly organized than honey bees. Members of bumble bee nests adhere to a hierarchy, beginning with the reproductive female, or queen. Bumble bee nests demonstrate divisions of labor, cooperative brood care, and overlapping generations within the colony. As an example, the bumble bee queen builds a nest and reproduces; her daughters then participate in brood care, foraging, and nest maintenance. Although bumble bees are used commercially (colonies can be purchased and shipped to different locations), as stated previously, other wild pollinators reside in unmanaged locations.

When a honey bee or a wild bee is foraging, it is searching for flowers. Flowers provide nutrition to bees in the form of pollen (protein) and nectar (carbohydrates) (Spivak, 2013). Nothing else feeds bees, except sugar water provided to honey bees by beekeepers, during times of food shortage. Not only do bees require flowers, most need a variety of floral resources in order to maintain health and fulfill nutritive requirements (Abrol, 2011; Goulson et al., 2015; Wackers and van Rijn, 2012). Bee generalists, who demonstrate "polylectic" behavior, collect pollen from a variety of unrelated resources (Ritchie et al., 2016). Most bees need a diversity of flowers, and a succession of bloom times, to support their life cycle throughout the spring, summer, and autumn (Persson and Smith, 2013; Williams et al., 2012). However, some pollinating insects exhibit "oligolecty", or floral specificity and harvest pollen only on a limited number of plant taxa (Ritchie et al., 2016; Robertson, 1925).

Pollinator populations have declined in recent years due to habitat fragmentation and loss, indiscriminate use of pesticides, widespread planting of agricultural monocultures, poor nutrition, the introduction of exotic pests and diseases, and climate change (Biesmeijer et al., 2006; Goulson et al., 2015). Severe declines in bee diversity, abundance, and ranges are concurrent with declines in bee-pollinated flowering plants (Murray et al., 2009; Biesmeijer et al., 2006; Potts et al., 2010). Environmental disturbances such as habitat fragmentation and loss are leading factors (Cameron et al., 2011; Murray et al., 2009). As humans become increasingly urbanized, native flora and fauna are displaced, and foraging opportunities for pollinators dwindle. If habitat is not completely destroyed, and remnants (fragments) remain, those fragmented and degraded habitats may be spatially prohibitive for pollinator survival (Goulson et al., 2015). In other words, the fragments may or may not include forage sights, nesting locations, and water resources.

Ironically, a major factor of pollinator decline is the very thing that keeps humans fed and clothed, which are monocultures (Alaux et al., 2010). Most monocultures lack the floral diversity that sustains pollinators (Brodschneider and Crailsheim, 2010). Swaths of corn, soybean, and cotton fields may benefit the human race, but they represent lack of nutrition to insects that depend upon floral resources (pollen and nectar) to survive. Monocultures are likened to vast food deserts to pollinators, whose only nutritive requirement are flowers (Spivak, 2013). Honey bees that are fed with pollen of various plants have healthier immune systems compared to bees that were pastured only on monocultures (Bekic et al., 2014). Polyfloral diets have been found to enhance honey bee immune functions and aid in better in-hive antiseptic protection (Alaux et al., 2010), which in turn creates a more pathogen resistant environment within the hive. Additionally, bees require a mixture of pollen from many different species of plants to ensure a balanced and diverse diet (Brodschneider and Crailsheim, 2010). Monocultures create nutritive deficiencies, which suppress the bee's immune system, and ultimately weakens the pollinating insect.

Poor nutrition due to loss of floral resources has caused the decline and extinction of some pollinator specialists, i.e. oligolectic insects that harvest pollen from a limited number of plant taxa (Murray et al., 2009; Goulson et al., 2015; Ritchie et al., 2016; Robertson, 1925). Reduction in the number and types of flowering plants needed to ensure good nutrition throughout a season, contribute as well. Bees are herbivores that feed their larvae with a mixture of pollen and nectar, or, rarely, plant oils (Michener, 2007). As flowers supply pollen and nectar, of the two, pollen is the most important for larval development. Honey bees, in particular, are completely dependent on pollen availability for brood-rearing (Brodschneider and Crailsheim, 2010). Critically, protein nutrition also moderates the impacts of honey bee pathogens, parasites, and overall resistance and resilience to stress factors (Alaux et al., 2010). Diets that include abundant, high quality pollen produce bees with stronger immune systems.

Honey bees, in particular, are under attack by pests and diseases, most notably the formidable varroa mite (*Varroa destructor*), imported from Asia and discovered in Wisconsin in 1987 (Hunt, 2010), and the tracheal mite (*Acarapis woodii*) first detected in Great Britain in 1921 (USDA, 2016). Varroa mite is an ectoparasite that clings to the body of the bee and sucks the hemolymph (blood), while vectoring viruses such as Black Queen Cell Virus (BQCV) and Deformed Wing Virus (DWV) (Moore et al., 2014). Tracheal mites, endoparasites, use their piercing mouthparts to penetrate the tracheal wall and feed on the hemolymph of the bee. Numerous mites in varying stages of growth are thought to restrict airflow within the trachea, effectively smothering the bee (USDA, 2016). *Nosema ceranae*, a microsporidian parasite, infects honey bee populations and pathogen spillover into wild bee populations has been observed (Graystock et al., 2013). Indeed, data suggest that the virulence of deformed wing virus might be higher in bumble bees than its original host, honey bees (Genersch et al., 2006).

Pollinator declines have also been directly linked to pesticide applications in agricultural systems. Neonicotinoids, which are widely used systemic insecticides, are thought to be especially damaging in that they are neurotoxic agents that affect the mobility of bees by inducing symptoms such as knockdown, trembling, uncoordinated movements, hyperactivity and tremors (Blacquiere et al., 2012). Bumble bees exposed to clothianidin exhibited reduced foraging activity, increased worker mortality, reproduced less, had lower worker survival rates, and reduced weight gain (Bekic et al., 2014; Hopwood et al., 2012; Larson et al., 2013). Imidacloprid, given direct exposure, is inherently toxic to honey bees (Schmuck et al., 2001). It has been demonstrated that honey bees subjected to even sub-lethal doses of neonicotinoids have trouble foraging, flying and navigating. Scientists with the United States Geographical Survey documented pesticide exposure in native bees collected from Colorado agricultural fields and grasslands. Pesticides were detected in the bees caught in grasslands with no known direct pesticide applications (Hladik et al., 2016), suggesting that pesticide exposure is ubiquitous. Additionally, recent studies have indicated that use of the fungicide chlorothalonil was the best predictor of pathogen *Nosema bombi* prevalence in four declining species of US bumble bees (McArt et al., 2017). Regarding the aforementioned solitary bees, which provision their nests with pollen balls: if the pollen is contaminated by pesticides in large doses, the chemical can be fatal to developing larvae (M. Spivak, personal communication, September 20, 2016).

All of these factors, including habitat fragmentation and loss, monocultures, poor nutrition, pests/diseases, and pesticide usage are believed to contribute to a complex known as Colony Collapse Disorder (CCD), specific to honey bees. This phenomenon exhibits as an abandoned colony or hive, with no adult worker bees present and no bee bodies evident but with a live queen, capped brood, honey, and immature bees still present (Bekic et al., 2014; United States Department of Agriculture, 2015). It has been suggested that one way honey bees regulate pathogen and parasite loads within a colony is for infected individuals to migrate en masse from their hive (Bekic et al., 2014; Van Engelsdorp et al., 2009). Although no single cause for CCD has been scientifically established, it is thought that all of these factors play a role.

The situation facing pollinators may seem insurmountable to individuals who express concern for pollinator health. With continued global population growth, intensive agricultural practices that rely on use of monocultures and pesticides will remain essential tools to feed the growing population. However, areas have been identified that might support habitat creation or restoration for endangered populations of honey bees, native bees, and other pollinating insects. They include: incorporating hedgerows, field margins, conservation buffer strips, and fallow fields into intensively cultivated agricultural landscapes (Gonigle et al., 2015; Wratten et al., 2012); restoration of hay meadows for plant-pollinator interactions (Forup and Memmott, 2005); prairie restorations for bee communities (an important component in wild bee conservation) (Tonietto et al., 2017); and habitat creation in urban settings (Shepherd et al., 2008). Another alternative for enhancing pollinator health and habitat is conservation of plants that are often considered weeds in various ecosystems. Such plants represent a substantial part of the pollinators' annual diet, providing pollen through their continuous flowering phenology and high species richness, contributing directly to pollinators need for pollen diversity (Requier, 2015). Since over sixteen 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), managed turfgrass ecosystems might be utilized for pollinator habitat.

Turfgrass

The annual value of the turfgrass industry in the United States is estimated at $40 to 60 billion (Fender, 2002; Hall et al., 2005). Although turfgrasses are often viewed as a monoculture, there are many turf systems where a diversity of monocot and dicot plants coexist (Gels et al., 2002; Larson et al., 2014). Turfgrass systems provide ecosystem services in the urban landscape, including carbon sequestration, oxygen production, erosion and dust control, reduction of heat island effects, aesthetics and recreation, water and pollutant filtration, and habitat for migratory species (Beard and Green, 1994; Thompson and Kao-Kiffin, 2017; BISE, 2010). Although turfgrass adds value to our environment through these ecosystem services, in the transition zone, warm-season turfgrasses can experience dormancy for up to six months out of the year. Low temperatures induce turfgrass dormancy and result in a loss of green color throughout the dormancy period (Patton, 2012), ranging from 4-6 months. Some find a dormant turf lackluster and bland. However, the practice of combining warm and cool season grasses is an established method of using both species to enhance aesthetics, and to lengthen sports field playability.

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, with advances of chemical herbicides and fertilizers in the mid-20th century, lawn mixtures that included legumes lost popularity and a more uniform aesthetic appearance became desirable. In the past seventy-five years, many weeds have been eliminated from the turfgrass ecosystem, removing floral resources for pollinators from the landscape (Larson et al., 2014). Some early-season bulbs, such as *Crocus* spp. and *Muscari* spp., provide foraging honey bees excellent sources of pollen and nectar in early spring (Steinkraus, 2010). White clover (*Trifolium repens* L.), and dandelion (*Taraxacum officinale*) are examples of flowering weeds which supply nutrition to pollinating insects, and can be included in mixed-use lawns as a form of reconciliation ecology (Larson, et al., 2014). Turfgrass ecosystems have the potential to create opportunities to attract and protect pollinators in the landscape, by incorporating an assortment of flowering plants (forbs) that supply nutrition to pollinating insects. Combining plants to create a succession of flowers throughout the growing season is the most beneficial scenario for pollinators.

Transition zone grasses include warm- and cool-season varieties. Bermudagrass (*Cynodon* spp.), a warm-season turfgrass, is the most commonly used lawn grass in Arkansas

(Boyd, 2016). Bermudagrass spreads by rhizomes and stolons, and has a dense growth habit and rapid growth rate. Buffalograss (*Buchloe dactyloides*), another warm-season turfgrass, is a slower growing, less aggressive, native turfgrass (Christians and Patton, 2017). Both are suitable lawn species in NW Arkansas, although buffalograss is not widely planted at this time.

Flowering Bulbs

Flowering bulbs are an important global commodity and Europe, the US Pacific Northwest, Japan, and Africa have climates that support a vast bulb industry (Bryan, 2002). Bulbs exist in many shapes and sizes, demonstrate a very short aboveground growth period (Khodorova and Boitel-Conti, 2013), and exhibit various bloom times throughout the growing season (Hessayon, 1996; Rees, 1992). Bulbs are defined as "geophyte", derived from the Greek, geo – earth, and phyton – plant (Raunkiaer, 1934). Ornamental geophyte are plant species that survive not only by seed but also by specialized underground storage organs (De Hertogh and Le Nard, 1993). Botanically, flowering bulbs consist of leaves or a stem altered or adapted for storage (Chrungoo et al., 1983). Because food reserves, nutrients, and moisture for the following year are collected in the underground repository, survival of the species is ensured (De Hertogh and Le Nard, 1993). The bulb is the underground nutrient storage structure from which the plant emerges, flowers, and senesces then spends the duration of dormancy underground.

Many popular flowering plants are generically described as bulbs, when in fact their storage structures may be more appropriately characterized as corms, tubers or rhizomes (Hessayon, 1996). True bulbs consist of layers of modified leaves and contain an embryo which is easily visible when a bulb is cut open through its center (Weston, 1931). A true bulb appears scaly and exhibits a basal plate from which roots extend. Examples of true bulbs include *Hyacinthus*, *Muscari*, and *Narcissus* spp. (De Hertogh and Le Nard, 1993). A corm, although a solid structure, exhibits a nutrient holding body that is a stem base (Hessayon, 1996) that has a basal plate with distinct nodes and internodes. Examples of corms are *Crocus* and *Gladiolus* spp. (De Hertogh and Le Nard, 1993). Tubers and rhizomes, also modified stems, do not demonstrate basal plates but have eyes or buds on the surface or neck of the stem (Weston, 1931). Examples of tubers and rhizomes are *Anemone*, *Eranthis*, and *Iris* spp. (De Hertogh and Le Nard, 1993). For the purpose of this paper, the term “bulb” will be used to discuss all of the storage structures, including true bulbs, corms, tubers and rhizomes (Khodorova and Boitel-Conti, 2013).

Recently, researchers were successful in the establishment of early-spring flowering bulbs in warm-season turfgrass lawns (Mirabile et al., 2016; Richardson et al., 2015). One species of bulb, *Crocus tommasinianus*, exhibited persistence and flowered over several years. Originally, researchers sought to investigate bulb persistence in competitive warm-season turfgrass environments, and effects on turfgrass biodiversity. However, very little is known about the ability of early-spring flowering bulbs to supply pollinator nutrition.

Some flowering bulbs are known to naturalize in grassy areas like meadows and pastures (Bryan, 2002). Naturalized bulbs must be hardy enough to compete with the grass, and grass systems must be managed in a way to not harm the bulbs, i.e. postponing mowing or grazing until bulb foliage has had time to senesce (Hessayon, 1996). When spent leaves senesce, they are translocating nutrients into the below-ground storage structure. However, in highly managed turfgrass systems, flowering bulbs may be unable to withstand common cultural practices such as mowing.

When planting bulbs, it is best to avoid small numbers of bulbs planted in a row, as mass plantings are considered more visually appealing (Dana et al., 2001; Curtis et al., 2009). Historically, traditional planting methods for bulbs required excavating a hole, inserting a bulb into the hole, and covering the bulb with loose soil. Although this is an appropriate method for a small quantity of bulbs, such as were used in previous studies (Richardson et al., 2015), when incorporating large numbers of bulbs into lawns or other expanses, in drifts or informal masses, this approach is both time consuming and labor intensive. Cutting turf as sod and rolling it back like a carpet, then laying bulbs in a random pattern on bare soil beneath has been suggested as an option for large plantings in grassy areas (Bryan, 2002; Hessayon, 1996). However, there have been no studies which have investigated methods of planting in dense, warm-season lawns. If the benefits of early-spring bulbs in lawns are going to be accepted and implemented by the public, efficient planting methods need to be developed.

Other Flowering Plants in Lawns

Numerous plants are commonly found in lawns that are considered forage sources for pollinators (Table 1). White clover is a low growing, perennial pasture legume with white flowers (Olsen et al., 2016), and is ubiquitous to managed turfgrass systems. Although viewed as a weed by many, white clover is considered a valuable source of nutrition for pollinators. Scientists working together from Auburn and Mississippi State Universities, and others at the University of Kentucky, have conducted studies incorporating white clover into lawns, to add nitrogen and potentially increase biodiversity and pollinator habitats within the turfgrass areas (Larson et al., 2014; McCurdy et al., 2013). The University of Minnesota recently established that white clover, self-heal (*Prunella vulgaris*), and wild thyme (*Thymus serpyllum*) can persist in hard fescue (*Festuca brevipila*), a cool-season grass, to supply pollinators with nutrition and forage sources in home lawns, or low-maintenance turf areas such as roadsides or cemeteries (Lane, 2016). Many homeowners have areas of turfgrass, or lawn, into which they might incorporate pollinator friendly forage plants. In addition, millions of acres of lower-maintenance turf exists on roadsides, in public or private parks, and on golf courses. All of these sites have potential to be transitioned into areas that encourage and enhance pollinator nutrition sources in the form of low growing flowering perennial plants. Legumes, such as red clover (*Trifolium pratense*), strawberry clover (*Trifolium fragiferum*), subterranean clover (*Trifolium subterraneum*), and white clover, not only add nitrogen to the turf (McCurdy et al., 2013; Sincik and Acikgoz, 2007), but are low-maintenance, sustainable solutions as food sources for pollinators (Larson et al. 2014; Cook, 2005). Herbaceous perennials, like English daisy (*Bellis perennis*), spring beauty (*Claytonia virginica*), and self-heal (*Prunella vulgaris*) have also proven to be pollinator friendly (Burkle, 2013; Cook, 2005; Lane, 2016; Oxford, 2018; Parker et al., 2016; Shepherd et al., 2008). Birds-foot trefoil (*Lotus corniculatus*), is a bee-pollinated leguminous species known to grow in poor soils in meadows and along highways (Cussans et al., 2010), and might be used to attract pollinators at restoration sites. Purple deadnettle (*Lamium purpureum*) and henbit (*Lamium amplexicaule*) are used by pollinators in early spring (Brown, 2016; Steinkraus, 2010), and both support honey bees and numerous species of native bees. Thistle (*Cirsium* spp.) may be considered a scourge by farmers, but is an important component of pasture and urban flower meadows because it is a valuable source of seeds for birds and other wildlife, plus pollen and nectar for bees and other pollinating insects (Hicks et al., 2016).

Generally, although the previously mentioned plants are considered to be weedy species, each is a source for pollinator nutrition and might be adapted or transitioned into lawns, roadsides, cemeteries, parks, and golf course out of play areas as sources of pollinator nutrition and habitat. It is our goal to identify and test herbaceous flowering perennial plants (forbs) to create a pollinator friendly plant list for home, land, or business owners who are interested in incorporating pollinator friendly practices into their lawn management systems.

As urbanized areas continue to expand, it is important to understand their capacity to support a diversity of pollinators and other beneficial insects. While many may see turfgrass ecosystems as monocultures, we view it as a significant opportunity to affect pollinator health. Turfgrass systems have many ecological benefits, and the U.S. has vast expanses of managed turfgrasses that might be transitioned into areas to attract and feed pollinating insects. Transitioned areas positively affect pollinator health by incorporating early-spring flowering bulbs and low growing flowering perennials into the turfgrass. Added benefits are cost savings passed on to municipalities and the federal government, by reducing the need for mowing and other general upkeep.

We seek to determine early-spring flowering bulbs that will persist in warm-season turfgrasses, to add color to dormant lawns while supplying pollen and nectar to early season pollinators like honey bees. We seek to identify forbs which will persist in bermudagrass as forage sources for pollinating insects. We seek to establish planting methods appropriate for incorporation of bulbs into grassy areas. Finally, we will combine data gathered from each of these studies, to support pollinator health by creating habitat and establishing the longest period of bloom time throughout the growing season.

Table 1. Examples of flowering plants which are/are not nutrition sources for pollinating insects.

Common name	**Scientific name**	**Pollinator forage rating**	**Reference**
White clover	*Trifolium repens*	3	Larson 2014
Crocus	*Crocus tommasinianus*	3	Steinkraus 2010
Spring beauty	*Claytonia virginica*	3	Burkle et al. 2013
Dandelion	*Taraxacum* spp.	3	Steinkraus 2010
Grape Hyacinth	*Muscari* spp.	3	Steinkraus 2010
Deadnettle	*Lamium purpureum*	2	Steinkraus 2010
Common Chickweed	*Stellaria media*	2	Steinkraus 2010
Daffodil	*Narcissus* spp.	1	Steinkraus 2010

Pollinator forage rating

1	no value to pollinators
2	moderate nutrition
3	excellent nutrition
na	no data available

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Early-Spring Flowering Bulbs in Warm-season Lawns

Abstract

Early-spring flowering bulbs can increase biodiversity while adding color to lawns and other grassy areas. However, few studies have determined whether flowering bulbs can persist in warm-season turfgrasses such as bermudagrass (*Cynodon dactylon*) and buffalograss (*Buchloe dactyloides*), while adding color and providing nutrition for pollinating insects. Thirty species of early-spring flowering bulbs, including *Anemone*, *Chionodoxa*, *Crocus*, *Eranthis*, *Hyacinthus*, *Ipheion*, *Iris*, *Leucojum*, *Muscari*, and *Narcissus*, were established in bermudagrass and buffalograss lawns, and a raised bed site, in fall 2015. Bulbs were assessed over two growing seasons (2016-2017) for flowering characteristics, persistence, and their ability to attract and feed pollinating insects. A growing degree day model was also developed to predict first flower and peak flowering times in Northwest Arkansas. Early performance was good with fourteen bulbs exhibiting >50% flower production in bermudagrass, eighteen bulbs exhibiting >50% flower production in buffalograss, and twenty-three bulbs exhibiting >50% flower production at the raised bed site in 2016. However, flower production fell in each study site in 2017. Four entries were identified that failed to persist over time in the turfgrass sites, including *Anemone blanda* ‘Pink Star’, *Eranthis hyemalis*, *Iris danfordiae*, and *Muscari neglectum*. Of these entries, *Eranthis hyemalis* and *Iris danfordiae* also failed in the raised bed, suggesting that they were not viable in Northwest Arkansas. Five bulb entries persisted in both turfgrasses and in the raised bed site (with >50% bulbs with flowers in 2017), including *Crocus flavus* ‘Golden Yellow’, *Leucojum aestivum*, *Narcissus* ‘Baby Moon’, *Narcissus* ‘Rip Van Winkle’, and *Narcissus* ‘Tete-a-Tete’. Of these entries, only one, *Crocus flavus* ‘Golden Yellow’, was observed to attract pollinating insects. However, various other species of *Crocus*, *Ipheion*, *Hyacinthus*, and *Muscari*

attracted pollinating insects throughout the study period. These results demonstrate that early-spring bulbs can persist in competitive warm-season turfgrasses, while feeding pollinators, but species and cultivar selection is critical for long-term success.

Introduction

Flowering bulbs

Flowering bulbs are an important horticultural crop and Europe, the US Pacific Northwest, Japan, and Africa have growing conditions that support a significant bulb industry (Bryan, 2002). Bulbs exist in many shapes and sizes and will demonstrate a short aboveground growth and bloom period (Khodorova and Boitel-Conti, 2013) that can occur at various times during the season (Hessayon, 1996; Rees, 1992). Bulbs are defined as "geophytes", derived from the Greek, geo – earth, and phyton – plant (Raunkiaer, 1934). Ornamental geophyte are plant species that survive not only by seed but also by specialized underground storage organs (De Hertogh and Le Nard, 1993). Botanically, flowering bulbs consist of leaves or a stem altered or adapted for storage (Chrungoo et al., 1983). Food reserves, nutrients, and moisture are stored in the underground organs and are an important component of survival (De Hertogh and Le Nard, 1993). The bulb is the underground nutrient storage structure from which the plant emerges, flowers, and senesces, before returning to an underground, dormant state.

Many plant species are generically described as bulbs, when in fact their storage structures may be more appropriately characterized as corms, tubers or rhizomes (Hessayon, 1996). True bulbs consist of layers of modified leaves and contain an embryo flower which is easily visible when the bulb is cut open through its center (Weston, 1931). A true bulb appears scaly and exhibits a basal plate from which roots extend. Examples of true bulbs include *Hyacinthus*, *Muscari*, and *Narcissus* spp. (De Hertogh and Le Nard, 1993). A corm, although a solid structure, exhibits a nutrient holding body that is a stem base (Hessayon, 1996) that has a basal plate with distinct nodes and internodes (De Hertogh and Le Nard, 1993). Examples of corms are *Crocus* and *Gladiolus* spp. Tubers and rhizomes, also modified stems, do not demonstrate basal plates but have eyes or buds on the surface or neck of the stem (Weston, 1931). Examples of tubers and rhizomes are *Anemone*, *Eranthis*, and *Iris* spp. (De Hertogh and Le Nard, 1993). For the purpose of this paper, the term “bulb” will be used to discuss all of these storage structures, including true bulbs, corms, tubers and rhizomes (Khodorova and Boitel-Conti, 2013).

Although there are various botanical forms that are considered bulbs, the common feature of all these species is a dormancy period, or state of suspended growth (Bryan, 2002). Dormancy is a complex and dynamic physiological, morphological, and bio-chemical state during which there is no apparent external morphological changes or growth (De Hertogh and Le Nard, 1993). However, during dormancy, physiological and morphological changes, such as “organogenesis” (i.e. differentiation of floral parts, etc.) occur within the bulb. Different bulb species flower at various times throughout the year and then experience a dormancy or resting period for the remainder of the year. Physiological changes within the storage structure are triggered by environmental cues such as light, moisture, and/or temperature fluctuations, and a vernalization period, or warm-cold-warm sequence (De Hertogh and Le Nard, 1993; Khodorova and Boitel-Conti, 2013). Like other plants, bulbs must reach a certain physiological stage before they have the ability to flower. After a juvenile phase, which might last from <1 - >6 years, the bulb achieves a “ripeness to flower” (De Hertogh and Le Nard, 1993), and blooms. An important component of successful bulb cultivation is the practice of permitting foliage to fully senesce before removal. As the leaves senesce, nutrients are translocated into the storage structure in preparation for dormancy (Hessayon, 1996). Premature removal of the foliage can weaken bulbs by reducing the amount of stored reserves.

Some flowering bulbs are known to naturalize in grassy areas like meadows and pastures (Bryan, 2002; Leeds, 2000). Naturalized bulbs must be hardy enough to compete with the grass, and grassy areas must be managed in a way to not harm the bulbs, i.e. postponing mowing or grazing until foliage has had time to senesce (Hessayon, 1996). As mentioned previously, when spent leaves weaken, they are translocating nutrients into the below-ground storage structure. However, in highly managed turfgrass systems, flowering bulbs may be unable to withstand common cultural practices such as mowing.

Turfgrass

Over sixteen 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). Although turfgrasses are often viewed as a monoculture, there are many turf systems where a diversity of monocot and dicot plants coexist (Gels et al., 2002; Larson et al., 2014). Turfgrass systems provide ecosystem services in the urban landscape, including carbon sequestration, oxygen production, erosion and dust control, reduction of heat island effects, water and pollutant filtration, and habitat for migratory species (Beard and Green, 1994; Thompson and Kao-Kiffin, 2017; BISE, 2010.). Although turfgrass adds value to our environment through these ecosystem services, in the transition zone, warm-season turfgrasses can experience dormancy for up to six months out of the year. Low temperatures induce turfgrass dormancy and result in a loss of green color throughout the dormancy period (Patton, 2012). Various species of flowering bulbs can complete their life cycle before a warm-season turfgrass breaks dormancy (Mirabile et al., 2016; Richardson et al., 2015). Two previous studies demonstrated that some flowering bulbs can persist in zoysiagrass (*Zoysia japonica* Steud.) and bermudagrass (*Cynodon dactylon* L. Pers) in the transition zone, providing color and biodiversity to dormant turfgrass situations (Mirabile et al., 2016; Richardson et al., 2015). However, neither study documented how this enhancement of biodiversity might affect other organisms in the system, such as soil fauna or beneficial insects such as pollinators.

Pollinators

Pollinators are important in that they move pollen from one plant to another, causing fruit set (Potts et al., 2010). Pollination services provide an integral part of human food production. The plant/pollinator relationship is mutually beneficial, as plants supply nourishment, in the form of pollen (protein) and nectar (carbohydrates), to the insect, while the insect ensures reproduction and survival in plants via seed and fruit set (Ollerton et al., 2011). Pollinator health is enhanced when diverse floral resources are available during the seasons when pollinators are active (Abrol, 2011; Goulson et al., 2015; Wackers and Van Rijn, 2012). Floral resources for pollinators can be found in the form of native or non-native plants (Decourtye et al., 2010), from weedy plant species to ornamentals such as flowering trees, shrubs, perennials and annuals. Pollinators (native and non-native) have suffered declines in the past several decades, due to an array of causes such as habitat and biodiversity loss, wide-spread planting of monocultures, pesticides, pests and diseases, and climate change (Biesmeijer et al., 2006; Goulson et al., 2015; Potts et al., 2010). Most critically, without appropriate (proper) floral resources, pollinators suffer from poor nutrition, and a diminished immune response to pest and disease pressure (Alaux et al., 2010). A key factor in incorporating pollinator forage into the landscape is to recognize that not all flowering plants are suitable selections for pollinator nutrition. Some flowers, although abundant, do not produce pollen and/or nectar. Maintaining a diversity of the correct season-long floral resources is essential to supporting a diversity of pollinating insects (Williams et al., 2015). Baseline habitat guidelines encourage the inclusion of at least three plants that flower at any given time during spring, summer, and/or fall (Vaughn and Skinner, 2015). Clumping single species together, and placing foraging habitat adjacent to nesting sites will also attract pollinating insects (Spivak et al., 2011). Significant expanses of managed turfgrasses, such as roadsides, cemeteries, and lawns, represent areas of land that might be designed and managed to feed 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, with advances of chemical herbicides and fertilizers in the mid-20th century, lawn mixtures that included legumes lost popularity and a more uniform aesthetic appearance became desirable. In the past seventy-five years, many weeds have been eliminated from the turfgrass ecosystem, removing floral resources for pollinators from the landscape (Larson et al., 2014). Some early season bulbs, such as *Crocus* and *Muscari* spp., provide foraging honey bees excellent sources of pollen and nectar in early spring (Steinkraus, 2010). Identifying bulb species that could add color to dormant warm-season turfgrasses, while supplying nutrition to pollinators, could fill two roles in many turfgrass ecosystems. If bulbs do not hinder or interfere with the majority of turfgrass cultural practices, they could provide alternatives to home and business owners interested in encouraging pollinator friendly habitats.

Recently, researchers at the University of Arkansas successfully established several species of early-spring bulbs in zoysiagrass, a warm-season turfgrass (Richardson et al., 2015). One species of bulb, *Crocus tommasinianus* ‘Ruby Giant’, was persistent in the lawn area and flowered over several years. These trials established proof of concept, but the minimal number of bulb species tested limits the broad application of the results. Additional work is needed to determine if other species or cultivars of early-spring bulbs can persist in warm-season lawns and determine if any of those species are favorable habitat for pollinating insects.

The objectives of the current study were as follows:

- Objective 1 – Identify early-spring flowering bulbs that can persist in warm-season turfgrasses
- Objective 2 – Determine if flowers produced by early-spring bulbs provide forage for pollinators
- Objective 3 - Determine if a growing-degree-day (GDD) model could predict flower emergence and peak flowering times

Materials and Methods

A field study was initiated on 19 Nov. 2015 at the University of Arkansas Agricultural Research and Experiment Center located in Fayetteville, AR (36:05:46.8 N, 94:10:28.5 W NAD83, 394 m 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 with amended soil covered by pine bark mulch, simulating a typical landscape planting bed. The sites were chosen to test differences in competitive habitats for the bulbs, as bermudagrass is a dense turfgrass with a rapid growth rate, while buffalograss is a less-dense, slower to establish, native turfgrass (Christians and Patton, 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. Mowing height of the bermudagrass and buffalograss areas was 7.5 cm and mowing was timed to every other week during the growing season. Mowing was initiated the second week of May each year, after turfgrass broke dormancy and new growth was evident. The turf received 7.5 g N/ m^2 (46-0-0, Thrive Branded Urea, Mears Fertilizer, Inc. El Dorado, KS), applied in July of each year. In the absence of rainfall, plots were irrigated during the summer months to supply 2.5 cm water / weekly.

Bulbs were chosen based on their reported mature height at bloom and their bloom time. In general, bulbs were chosen that have a mature height of less than 15 cm and complete their life cycle before April/May when mowing would be initiated. Thirty bulb species were tested in this trial (Table 1) and were purchased from 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 planting area. Plots established in the turfgrass sites measured 0.9 x 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 x 0.9 m area in the center of the plot, with buffers between plots. Plot size in the raised bed was 0.6 x 0.6 m, with 3 replicates per bulb entry, and 25 bulbs per replicate. Templates were constructed for each plot size and were used to mark each planting site, by spraying paint through pre-cut holes. Holes were dug either by hand or with the aid of an auger attached to a cordless drill, depending on the bulb size. Bulbs were planted to approximately twice the depth of the length of the bulb, and covered with loose soil. The project control was *Crocus tommasinianus* 'Ruby Giant', a previously tested early-spring flowering bulb that demonstrated persistence in zoysiagrass at this location (Richardson et al., 2015).

Data collection was primarily focused on establishment, performance, and persistence of bulbs over a two-year period (2016-2017). Each treatment was evaluated for first flower date, peak flower date, and flowering abundance (% of bulbs with flowers). Data collection consisted of weekly counts of plant emergence, flower emergence, and pollinator activity (if present).

When assessing pollinator activity, each treatment was visually inspected for pollinator presence. Pollinators that visited a flower and foraged were counted, while pollinators that did not forage were not counted. Foraging was defined as intentional feeding upon pollen or nectar in the flower and pollinator activity counts were taken in one minute increments. Pollinating insects were characterized as members of Hymenoptera (honey bees, bumble bees, wasps, ants), Lepidoptera (butterflies), or “other” including Diptera (flies), and Coleoptera (beetles).

First flower and peak flower of each entry were modeled against accumulated growing degree days, using the following equation based on air temperature:

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

Base temperatures are those below which growth does not occur (Gilmore and Rogers, 1958). However, bulbs experience a complex and dynamic physiological, morphological and bio-chemical state during periods of low temperatures (dormancy) such as flower or root differentiation via organogenesis (De Hertogh and Le Nard, 1993). Bulb dormancy in winter is broken by a period of several weeks at low temperature, approximately 4° C (Langens-Gerrits et al., 2003). Accordingly, the base temperature in the growing degree day equation was assigned 0° C to ensure proper representation of bulb dormancy.

The three planting sites were not replicated and were analyzed independently by analysis of variance, with mean separation tests performed using Fisher’s protected least significant difference (P=0.05). Analysis of variance was performed to test the effects of block, bulb entry, and year on flowering characteristics of early-spring bulbs in bermudagrass and buffalograss lawns, and a raised bed. In addition, regression analysis was used to determine if GDD estimates of first flower and peak flower in the first year of the trial were good predictors of those parameters in the second year of the trial.

Results and Discussion

As mentioned, since sites were not replicated, all statistical analyses were performed by site. Analysis of variance indicated a significant effect of year and entry on first flowering date, peak flowering date, and number of blooms with flowers for each site (Table 2). In addition, there was a significant year x 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 cultivar within year for each site.

For the purposes of this paper, first flower day of year (DOY) and growing-degree-day units (GDD) required will be noted in their abbreviated form. Finally, when referencing success and failure within the parameters of this paper, success was defined as >50% bulbs with flowers after two growing seasons, with failure defined as <10% bulbs with flowers after two growing seasons.

Bulb performance in a bermudagrass lawn

In 2016, flower emergence occurred over a three-month period, from January through May (Table 3). *Iris danfordiae* was the first bulb to produce flowers in 2016, commencing on 31 January, with a corresponding GDD requirement of 163 units. In 2017, flower emergence shifted, occurring earlier in January and ending in April (Table 4). *Crocus flavus* ‘Golden Yellow’ was the first bulb to produce flowers in 2017, on 25 Jan, with a corresponding GDD requirement of 170 units. Overall, the bulbs achieved peak flower (DOY and GDD) at various times throughout the experimental period, with the greatest number of bulbs peaking the second and third weeks in March 2016, and the fourth week of February 2017.

In 2016, five species of bulbs produced greater than 90% flowers, including *Crocus chrysanthus* ‘Blue Pearl’, *Crocus chrysanthus* ‘Cream Beauty’, *Crocus flavus* ‘Golden Yellow’, *Hyacinthus orientalis* ‘Pink Pearl’, and *Narcissus* ‘Rip Van Winkle’ (Table 3). However, in 2017, none of the entries demonstrated >90% bulbs with flowers, and only species of *Crocus*, *Leucojum*, and *Narcissus* showed >50% flowering in bermudagrass (Table 4). The entries which showed the greatest persistence over time in bermudagrass included *Crocus flavus* ‘Golden Yellow’, *Leucojum aestivum*, *Narcissus* ‘Baby Moon’, *Narcissus* ‘Rip Van Winkle’, and *Narcissus* ‘Tete-a-Tete’. Several entries, including *Hyacinthus orientalis* ‘Pink Pearl’, *Muscari aucheri* ‘Mount Hood’, and *Muscari neglectum* produced abundant flowers (>70%) in 2016 (Table 3), but did not produce significant flowers (<20%) in 2017 (Table 4).

Several species of early spring flowering bulbs did not persist in bermudagrass, including *Anemone* spp., *Chionodoxa* spp., *Eranthis hyemalis*, *Iris danfordiae*, *Hyacinthus orientalis*, and *Muscari neglectum* (<10% bulbs with flowers in 2017, Table 4). As a whole, *Narcissus* demonstrated the ability to persist and flower in bermudagrass to a greater degree than other entries; *Crocus*, *Ipheion*, *Leucojum*, and *Muscari* also showed ability to persist over time but further study is required to gauge overall endurance of these entries.

Bulb performance in a buffalograss lawn

In 2016, flower emergence occurred over a three-month period, from February through May (Table 5). *Iris danfordiae* was the first bulb to produce flowers, commencing on 1 February, with a corresponding GDD requirement of 172 units. In 2017, flower emergence was earlier, beginning in January and ending in April (Table 6). *Crocus chrysanthus* ‘Cream Beauty’ and *Crocus olivieri balansae* ‘Zwanenburg’ were the first bulbs to produce flowers, on 22 January, with a corresponding GDD requirement of 147 units. Overall, the bulbs achieved peak flower (DOY and GDD) at various times throughout the experimental period, with the greatest number of bulbs peaking the second week of March 2016 (Table 5), and the third week of February 2017 (Table 6).

In 2016, data from the buffalograss site indicated five species with >90% bulbs with flowers including *Muscari armeniacum, Muscari neglectum*, *Narcissus* 'Rijnveld's Early Sensation', *Narcissus* 'Rip Van Winkle', and *Narcissus* 'Tete-a-Tete'(Table 5). However, by 2017, only two species of *Narcissus*, 'Tete-a-Tete' and 'Baby Moon', produced flowers on >90% bulbs (Table 6). It is important to note that ten additional entries in buffalograss retained >50% bulbs with flowers in 2017, compared to only five entries in bermudagrass for the same period (Table 4). One entry, *Muscari neglectum*, produced abundant flowers in 2016 (>70%), but did not produce significant flowers in 2017 (<20%).

Several species of early spring flowering bulbs performed poorly over the two years in buffalograss. In 2017, *Anemone blanda* 'Pink Star', *Eranthis hyemalis, Iris danfordiae,* and *Muscari neglectum*, exhibited <10% bulbs with flowers (Table 6). As a whole, *Narcissus* spp. and other *Muscari* spp. demonstrated the ability to persist and flower in buffalograss to a greater degree than other entries.

Bulb performance in a raised bed

In 2016, flower emergence occurred over a three month period, from February through May (Table 7). Seven species of bulbs were the first to produce flowers, commencing on 23 February, with a corresponding GDD requirement of 280 units. Bulbs that flowered on 23 February 2016 included *Crocus chrysanthus* 'Blue Pearl', *Crocus chrysanthus* 'Cream Beauty', *Crocus flavus* 'Golden Yellow', *Crocus seiberi* 'Tricolor', *Iris danfordiae, Iris histrioides* 'Katherine Hodgkin', and *Narcissus* 'Rijnveld's Early Sensation'. In 2017, flower emergence shifted, beginning in January and ending in April (Table 8). *Crocus olivieri balansae*

‘Zwanenburg’ was the first bulb to produce flowers on 25 January, with a corresponding GDD requirement of 170 units. Overall, the bulbs achieved peak flower (DOY and GDD) at various times throughout the experimental period, with the greatest number of bulbs peaking the second week in March 2016, and the fourth week in February, and fourth and fifth weeks in March, 2017.

In 2016, bulb data from the raised bed site indicated eight species with >90% bulbs with flowers including *Crocus flavus* ‘Golden Yellow’, *Crocus vernus* ‘Flower Record’, *Muscari armeniacum*, *Muscari aucheri* ‘Mount Hood’, *Muscari neglectum, Narcissus* ‘Rijnveld’s Early Sensation’, *Narcissus* ‘Rip Van Winkle’, and *Narcissus* ‘Tete-a-Tete’ (Table7). Six species produced >80% bulbs with flowers, including *Crocus chrysanthus* ‘Blue Pearl’, *Crocus chrysanthus* ‘Cream Beauty’, *Crocus tommasinianus ‘Ruby Giant’, Hyacinthus orientalis* ‘Pink Pearl’, *Leucojum aestivum,* and *Narcissus* ‘Baby Moon’. Four species produced >70% bulbs with flowers and included *Crocus seiberi* ‘Tricolor’, *Crocus vernus* ‘Remembrance’, *Chionodoxa sardensis,* and *Narcissus caniculatus*. However, by 2017, only *Leucojum aestivum* exhibited >90% bulbs with flowers, and many had fallen to the 50% range (Table 8). Several entries, including *Chionodoxa sardensis*, *Crocus sieberi* ‘Tricolor’, *Hyacinthus orientalis* ‘Pink Pearl’, and *Muscari neglectum* produced abundant flowers in 2016 (>70%), but did not produce significant flowers in 2017 (<20%).

Six species of early spring flowering bulbs demonstrated lack of persistence in the raised bed site over two years. *Crocus olivieri balansae* ‘Zwanenburg’, *Crocus seiberi* ‘Tricolor’, *Eranthis hyemalis, Iris danfordiae, Iris histrioides* ‘Katherine Hodgkin’, and *Hyacinthus orientalis* ‘Pink Pearl’ exhibited <10% bulbs with flowers in 2017 (Table 8).

Entries which failed (<10% bulbs with flowers) in both turfgrass sites included *Anemone blanda* ‘Pink Star’, *Eranthis hyemalis*, *Iris danfordiae*, and *Muscari neglectum*. Two of these entries, *Eranthis hyemalis* and *Iris danfordiae*, also failed in the raised bed, suggesting that they are not viable in Northwest Arkansas (Table 8). *Anemone blanda* ‘Pink Star’ and *Muscari neglectum* managed to persist in the raised bed, but were unable to perform in the competitive turfgrass environments. However, five bulb entries succeeded in persisting in both turfgrasses and the raised bed sites (with >50% bulbs with flowers in 2017), including *Crocus flavus* ‘Golden Yellow’, *Leucojum aestivum*, *Narcissus* ‘Baby Moon’, *Narcissus* ‘Rip Van Winkle’, and *Narcissus* ‘Tete-a-Tete’.

Previous studies demonstrated 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). While a transition zone occurs in the Italian Peninsula, in areas at latitudes between the Po Valley to Sicily (Mirabile et al., 2016), and corresponds to temperatures within the transition zone of the United States, it follows that research in early-spring flowering bulbs within the two similar planting zones might corroborate each other. *Narcissus* ‘Rip Van Winkle’ was tested in both studies and showed persistence over time in transition zones in the United States and Italy.

Research 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 the transition zone in Arkansas (zone 6b, 7a: -20.6° to -15° C), persisted and flourished in those cooler climates. In Ithaca, *Anemone blanda*, *Hyacinthus orientalis*, and *Ipheion uniflorum* are recorded on Cornell’s Best 15 Bulbs &

Perennial Combinations List (Cornell University, 2007). At the University of Kentucky, *Anemone blanda*, *Chionodoxa*, *Crocus vernus*, *Iris danfordiae*, and *Narcissus jonquilla* are recommended flower bulbs for Kentucky gardens (Anderson, 2004). And in West Lafayette, *Anemone blanda*, *Chionodoxa*, *Eranthis hyemalis*, *Hyacinthus orientalis*, *Ipheion uniflorum*, and *Iris danfordiae* are recommended as bulbs suitable for Indiana gardens (Dana, 2001). Each entry noted above fell well below the 50% margin for success in NW Arkansas. None of these selections persisted over time in warm-season turfgrasses, suggesting either transition zone temperatures are too high, or the competitive conditions within the turfgrass environment limited successful bulb establishment.

Growing Degree Day Models

Regression analysis was used to determine if GDD estimates of first flower and peak flower in the first year of the trial were good predictors of those parameters in the second 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.

In the bermudagrass site (Figure 1), a linear relationship was observed between the 2016 and 2017 GDD units for both dates to first flower and peak flower ($P<0.001$). However, correlations between variables were not strong and only accounted for about 50% of the variation in the data for both categories ($r^2 = 0.55$ GDD to first flower; $r^2 = 0.50$ GDD to peak flower).

In the buffalograss site (Figure 2), a linear relationship was also observed between the 2016 and 2017 GDD units for both dates to first flower and peak flower ($P<0.001$). However, correlations were not strong and accounted for less than 50% of the variation in the data for both categories ($r^2 = 0.48$ GDD to first flower; $r^2 = 0.46$ GDD to peak flower).

Heat accumulation in the spring is commonly used to predict the timing of phenological transitions in plants and animals (USA-NPN, 2018). Temperature has a significant impact on the rate of development of crops and many other organisms (Payero, 2017), and is commonly used to hasten or delay development of flowering bulbs (De Hertogh and Le Nard, 1993). Although the GDD data from the first year of the trial were correlated to GDD responses in the second year, additional research is needed to determine if these models will be predictive of bulb flowering in other locations. Studies would need to be conducted outside of the present region to see if the models developed here can predict flowering periods elsewhere. As GDD models are developed to predict flowering bulb behavior in targeted geographic locations, they could be useful for making appropriate recommendations to interested parties or entities for flowering bulbs best suited to their particular planting zone. Additionally, GDD models might be tested and developed in various other turfgrass situations, such as cool-season turfgrass sites, to ensure best management practices for flowering bulbs outside of the transition zone.

Pollinator Activity in bermudagrass, buffalograss, and raised bed

Although native bees and other pollinators are typically not active during winter months, honey bees will forage on mild winter days, though they may be limited by temperature to short distance flights (Hodges, 1952). Pollinator activity counts were taken when weather permitted and all data were analyzed by site and year and are presented to show the effects of cultivar within year for each site. It is important to note that pollinator activity may have occurred on flowers, undetected by the observer, due to time limitations, and/or changes in weather patterns throughout the day or week.

In bermudagrass, pollinator activity was observed in 2016 exclusively on three species of grape hyacinth including *Muscari* ‘Valerie Finnis’, *Muscari armeniacum*, and *Muscari aucheri*

‘Mount Hood’ (Table 9, Figure 3). In 2017, pollinators favored *Crocus chrysanthus* ‘Blue Pearl’, *Crocus flavus* ‘Golden Yellow’ (Figure 4), and *Ipheion uniflorum* ‘Rolf Fiedler’ (Table 9).

In buffalograss, pollinator activity was observed in 2016 exclusively on three species of grape hyacinth, including *Muscari* ‘Valerie Finnis’, *Muscari armeniacum,* and *Muscari neglectum* (Table 10). In 2017, pollinators favored *Crocus chrysanthus* ‘Blue Pearl’ and ‘Cream Beauty’, *Crocus flavus* ‘Golden Yellow’, *Crocus isauvicus* ‘Spring Beauty’, *Crocus vernus* ‘Remembrance’, *Hyacinthus orientalis* ‘Pink Pearl’, *Ipheion uniflorum*, *Muscari armeniacum*, and *Muscari aucheri* ‘Mount Hood’ (Table 10).

In the raised bed, pollinator activity was observed in 2016 on *Chionodoxa sardensis*, *Muscari* ‘Valerie Finnis’, *Muscari armeniacum*, *Muscari aucheri* ‘Mount Hood’, and *Muscari neglectum*. In 2017, pollinators favored *Ipheion uniflorum*, *Muscari* ‘Valerie Finnis’, *Muscari armeniacum*, *Muscari aucheri* ‘Mount Hood’, and *Narcissus caniculatus* (data not shown).

Conclusions

Thirty early-spring flowering bulbs were tested over a 2-year period in bermudagrass and buffalograss in Northwest Arkansas. This study demonstrated that several bulb species can both persist in warm-season turfgrasses and supply nutrition to pollinating insects. The benefit to pollinators confirms another potential ecosystem service of lawns in both urban and rural environments. Further research 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 into 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 *Poa*, *Festuca*, or *Lolium* spp. and this would be a logical avenue for future research, since cool-season lawns occupy most temperate climates of the world. 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.

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

Scientific Name	Cultivar (if known)	Common Name
Anemone blanda	Blue Shades	windflower, thimbleweed
Anemone blanda	Pink Star	windflower, thimbleweed
Chionodoxa forbesii	Pink Giant	glory of the snow
Chionodoxa sardensis		glory of the snow
Crocus chrysanthus	Blue Pearl	snow crocus
Crocus chrysanthus	Cream Beauty	snow crocus
Crocus flavus	Golden Yellow	crocus
Crocus isauvicus	Spring Beauty	snow crocus
Crocus olivieri balansae	Zwanenburg	snow crocus
Crocus sieberi	Tricolor	Sieber's crocus
Crocus tommasinianus	Ruby Giant	snow crocus
Crocus vernus	Remembrance	spring crocus
Crocus vernus	Flower Record	spring crocus
Eranthis hyemalis		winter aconite
Hyacinthus orientalis	Pink Pearl	hyacinth
Ipheion uniflorum		spring starflower
Ipheion uniflorum	Rolf Fiedler	spring starflower
Iris danfordiae		iris
Iris histrioides	Katherine Hodgkin	iris
Leucojum aestivum		spring snowflake
Muscari	Valerie Finnis	grape hyacinth
Muscari armeniacum		grape hyacinth
Muscari aucheri	Mount Hood	grape hyacinth
Muscari neglectum		grape hyacinth
Narcissus	Rijnveld's Early Sensation	trumpet daffodil (Div 1)
Narcissus	Rip Van Winkle	double daffodil (Div 4)
Narcissus	Tete-a-Tete	cyclamineus daffodil (Div 6)
Narcissus	Baby Moon	jonquilla daffodil (Div 7)
Narcissus canaliculatus		miniature daffodil (Div 13)
Narcissus jonquilla simplex		miniature daffodil (Div 13)

Table 2. Analysis of variance, testing the effects of year, block, and bulb entry on flowering characteristics of spring bulbs in a bermudagrass lawn, a buffalograss lawn, and a raised landscape bed.

Source	DF[z]	First flower		Peak flower		No. of plants
		DOY[y]	GDD[x]	DOY	GDD	with flowers (%)
		--------------------------------	Pr > F	-----------------------------------		
Bermudagrass						
Year	1	<.0001	<.0001	<.0001	<.0001	<.0001
Block	2	0.0008	0.0002	0.1681	0.0684	0.2312
Entry	29	<.0001	<.0001	<.0001	<.0001	<.0001
Year*Entry	29	<.0001	<.0001	<.0001	<.0001	<.0001
Buffalograss						
Year	1	<.0001	0.0001	<.0001	<.0001	<.0001
Block	2	0.5056	0.7821	0.6748	0.8761	0.0376
Entry	29	<.0001	<.0001	<.0001	<.0001	<.0001
Year*Entry	29	<.0001	<.0001	<.0001	<.0001	<.0001
Raised Bed						
Year	1	<.0001	0.0012	<.0001	<.0001	<.0001
Block	2	0.0109	0.0188	0.6161	0.5786	0.3358
Entry	29	<.0001	<.0001	<.0001	<.0001	<.0001
Year*Entry	29	<.0001	<.0001	<.0001	<.0001	<.0001

[z] DF = degrees of freedom
[y] DOY = Day of Year
[x] GDD = Growing degree day units, with a base temperature of 0°C

Table 3. Effects of various spring bulb entries on day of year (DOY) and growing degree day units (GDD) to first observed flowers, DOY and GDD to peak flower, and percentage of twenty-five planted bulbs that produced flowers in a bermudagrass lawn (2016 data).

Scientific Name	Cultivar (if known)	First flower	First flower	Peak flower	Peak flower	bulbs w/ flowers
		DOY	GDD	DOY	GDD	%
Crocus flavus	Golden Yellow	47.3	260.8	53.3	316.1	98.7
Hyacinthus orientalis	Pink Pearl	71.0	490.5	74.0	530.4	98.7
Narcissus spp.	Rip Van Winkle	71.0	490.5	74.0	530.4	97.3
Crocus chrysanthus	Blue Pearl	39.0	206.6	53.3	316.1	96.0
Crocus chrysanthus	Cream Beauty	47.3	260.8	53.3	316.1	96.0
Narcissus spp.	Tete-a-Tete	52.0	307.4	71.0	490.5	89.3
Iris histrioides	Katherine Hodgkin	47.3	260.8	52.0	307.4	88.0
Muscari aucheri	Mount Hood	74.0	530.4	74.0	530.4	85.3
Muscari neglectum		57.0	358.4	74.0	530.4	80.0
Narcissus spp.	Rijnveld's Early Sensation	52.0	307.4	65.0	424.9	78.7
Muscari armeniacum		74.0	530.4	74.0	530.4	77.3
Crocus sieberi	Tricolor	47.3	260.8	52.0	307.4	64.0
Leucojum aestivum		74.0	530.4	74.0	530.4	64.0
Narcissus canaliculatus		74.0	530.4	74.0	530.4	54.7
Crocus isauvicus	Spring Beauty	52.0	307.4	68.0	450.6	46.7
Iris danfordiae		31.0	162.8	47.3	260.8	41.3
Crocus tommasinianus	Ruby Giant	68.0	450.6	68.0	450.6	40.0
Crocus vernus	Rememberence	68.0	450.6	68.0	450.6	37.3
Crocus olivieri balansae	Zwanenburg	49.7	284.1	57.7	350.6	36.0
Narcissus jonquilla simplex		88.0	689.0	88.0	689.0	32.0
Chionodoxa sardensis		52.0	307.4	74.0	530.4	30.7
Anemone blanda	Blue Shades	74.0	530.4	88.0	689.0	29.3
Crocus vernus	Flower Record	58.5	359.1	58.5	359.1	24.0
Muscari spp.	Valerie Finnis	74.0	530.4	74.0	530.4	20.0
Anemone blanda	Pink Star	88.0	689.0	88.0	689.0	17.3
Chionodoxa forbesii	Pink Giant	74.0	530.4	74.0	530.4	16.0
Ipheion uniflorum	Rolf Fiedler	81.0	609.7	88.0	689.0	8.0
Eranthis hyemalis		65.0	410.7	65.0	410.7	6.7
Ipheion uniflorum		110.0	750.0	110.0	750.0	4.0
Narcissus spp.	Baby Moon	.	.	.	.	0.0
	LSD (0.05)†	6.4	68.0	5.5	58.9	25.0

† LSD = least significant difference values ($\alpha = 0.05$) for comparing means within a column.

Table 4. Effects of various spring bulb entries on day of year (DOY) and growing degree day units (GDD) to first observed flowers, DOY and GDD to peak flower, and percentage of twenty-five planted bulbs that produced flowers in a bermudagrass lawn (2017 data).

Scientific Name	Cultivar (if known)	First flower	First flower	Peak flower	Peak flower	bulbs w/ flowers
		DOY	GDD	DOY	GDD	%
Narcissus spp.	Tete-a-Tete	50.0	396.0	57.0	475.0	89.3
Narcissus spp.	Baby Moon	87.3	802.3	96.0	933.0	85.3
Leucojum aestivum		82.0	729.0	92.0	870.3	80.0
Narcissus spp.	Rip Van Winkle	54.7	448.7	68.0	577.0	66.7
Crocus flavus	Golden Yellow	25.3	170.3	45.0	323.0	57.3
Crocus tommasinianus	Ruby Giant	60.7	508.7	68.0	577.0	49.3
Crocus vernus	Rememberence	46.7	347.3	50.0	396.0	48.0
Narcissus spp.	Rijnveld's Early Sensation	52.3	422.3	60.7	509.0	38.7
Crocus chrysanthus	Blue Pearl	34.7	231.0	45.0	323.0	36.0
Iris histrioides	Katherine Hodgkin	42.3	298.3	49.0	373.7	33.3
Narcissus canaliculatus		50.0	396.0	54.7	448.7	32.0
Muscari armeniacum		70.3	586.7	84.7	765.7	30.7
Crocus isauvicus	Spring Beauty	45.0	323.0	50.0	396.0	29.3
Crocus vernus	Flower Record	46.7	347.3	52.3	422.3	28.0
Muscari spp.	Valerie Finnis	84.7	765.7	90.0	839.0	26.7
Narcissus jonquilla simplex		82.0	729.0	84.7	765.7	26.7
Crocus sieberi	Tricolor	46.3	349.0	52.3	422.3	24.0
Crocus chrysanthus	Cream Beauty	45.0	340.0	56.0	456.3	21.3
Muscari aucheri	Mount Hood	72.7	597.3	82.0	729.0	20.0
Ipheion uniflorum	Rolf Fiedler	64.3	542.3	82.0	729.0	17.3
Ipheion uniflorum		87.3	802.3	90.0	839.0	13.3
Chionodoxa sardensis		60.7	508.7	69.0	593.7	9.3
Crocus olivieri balansae	Zwanenburg	41.0	286.0	41.0	286.0	4.0
Chionodoxa forbesii	Pink Giant	68.0	576.0	68.0	577.0	1.3
Hyacinthus orientalis	Pink Pearl	50.0	396.0	50.0	396.0	1.3
Iris danfordiae		50.0	396.0	50.0	396.0	1.3
Anemone blanda	Blue Shades	.	.	.	.	0.0
Anemone blanda	Pink Star	.	.	.	.	0.0
Eranthis hyemalis		.	.	.	.	0.0
Muscari neglectum		.	.	.	.	0.0
	LSD (0.05)	9.7	100.6	7.6	84.2	26.1

† LSD = least significant difference values (α = 0.05) for comparing means within a column.

Table 5. Effects of various spring bulb entries on day of year (DOY) and growing degree day units (GDD) to first observed flowers, DOY and GDD to peak flower, and percentage of twenty-five planted bulbs that produced flowers in a buffalograss lawn (2016 data).

Scientific Name	Cultivar (if known)	First flower	First flower	Peak flower	Peak flower	bulbs w/ flowers
		DOY	GDD	DOY	GDD	%
Narcissus spp.	Rip Van Winkle	71.0	485.3	71.0	485.3	100.0
Narcissus spp.	Tete-a-Tete	52.0	307.4	71.0	485.3	98.7
Narcissus spp.	Rijnveld's Early Sensation	47.3	271.2	71.0	485.3	93.3
Muscari armeniacum		71.0	485.3	71.0	485.3	92.0
Muscari neglectum		52.0	307.4	64.7	425.9	90.7
Crocus chrysanthus	Cream Beauty	45.0	237.5	53.0	313.2	86.7
Hyacinthus orientalis	Pink Pearl	71.0	485.3	71.0	485.3	86.7
Muscari aucheri	Mount Hood	71.0	485.3	71.0	485.3	86.7
Crocus chrysanthus	Blue Pearl	39.0	206.6	53.0	313.2	84.0
Crocus flavus	Golden Yellow	47.3	260.8	54.0	319.4	80.0
Crocus olivieri balansae	Zwanenburg	45.0	237.5	54.0	319.4	80.0
Leucojum aestivum		71.0	485.3	71.0	485.3	80.0
Iris histrioides	Katherine Hodgkin	49.7	284.1	52.0	307.0	74.7
Muscari spp.	Valerie Finnis	71.0	485.3	71.0	485.3	74.7
Narcissus canaliculatus		71.0	485.3	71.0	485.3	74.7
Chionodoxa forbesii	Pink Giant	71.0	485.3	71.0	485.3	57.3
Crocus tommasinianus	Ruby Giant	62.3	402.7	62.3	402.9	57.3
Crocus vernus	Rememberence	71.0	485.3	71.0	485.3	53.3
Crocus sieberi	Tricolor	52.0	307.4	55.0	325.6	49.3
Chionodoxa sardensis		58.3	366.7	71.0	485.3	46.7
Anemone blanda	Blue Shades	76.7	553.2	88.0	689.0	45.3
Iris danfordiae		32.7	172.2	52.0	307.0	34.7
Crocus isauvicus	Spring Beauty	52.0	307.4	59.3	372.6	29.3
Crocus vernus	Flower Record	71.0	485.3	71.0	485.3	28.0
Narcissus jonquilla simplex		88.0	689.0	88.0	689.0	20.0
Eranthis hyemalis		58.3	366.7	64.7	425.9	9.3
Anemone blanda	Pink Star	88.0	689.0	88.0	689.0	5.3
Ipheion uniflorum	Rolf Fiedler	88.0	689.0	88.0	689.0	2.7
Ipheion uniflorum		.	.	.	.	1.3
Narcissus spp.	Baby Moon	.	.	.	.	0.0
	LSD (0.05)†	8.5	82.0	7.8	73.8	17.2

† LSD = least significant difference values (α = 0.05) for comparing means within a column.

Table 6. Effects of various spring bulb entries on day of year (DOY) and growing degree day units (GDD) to first observed flowers, DOY and GDD to peak flower, and percentage of twenty-five planted bulbs that produced flowers in a buffalograss lawn (2017 data).

Scientific Name	Cultivar (if known)	First flower	First flower	Peak flower	Peak flower	bulbs w/ flowers
		DOY	GDD	DOY	GDD	%
Narcissus spp.	Tete-a-Tete	50.0	396.0	57.0	475.0	97.3
Narcissus spp.	Baby Moon	92.0	870.3	98.3	976.3	96.0
Crocus flavus	Golden Yellow	25.3	170.3	45.0	323.0	85.3
Leucojum aestivum		82.0	729.0	90.0	839.0	85.3
Muscari armeniacum		68.0	577.0	82.0	729.0	84.0
Crocus chrysanthus	Cream Beauty	22.7	146.7	42.3	298.3	81.3
Muscari aucheri	Mount Hood	57.0	475.0	75.0	608.0	77.3
Narcissus spp.	Rip Van Winkle	57.0	475.0	68.0	576.0	76.0
Crocus chrysanthus	Blue Pearl	27.7	182.7	45.0	323.0	74.7
Narcissus canaliculatus		50.0	396.0	60.7	508.7	57.3
Crocus tommasinianus	Ruby Giant	57.0	475.0	68.0	576.0	53.3
Narcissus spp.	Rijnveld's Early Sensation	50.0	396.0	60.7	508.7	52.0
Crocus isauvicus	Spring Beauty	32.3	213.0	45.0	323.0	49.3
Muscari spp.	Valerie Finnis	82.3	725.3	92.0	870.3	48.0
Crocus sieberi	Tricolor	45.0	323.0	45.0	323.0	44.0
Iris histrioides	Katherine Hodgkin	42.3	298.3	46.7	347.3	42.7
Crocus olivieri balansae	Zwanenburg	22.7	146.7	32.3	213.0	41.3
Hyacinthus orientalis	Pink Pearl	42.3	298.3	56.0	456.0	33.3
Ipheion uniflorum		64.3	543.0	84.7	765.7	33.3
Crocus vernus	Rememberence	54.7	448.7	64.3	542.3	26.7
Ipheion uniflorum	Rolf Fiedler	64.3	543.0	75.0	637.7	26.7
Crocus vernus	Flower Record	49.0	373.7	60.7	508.7	25.3
Narcissus jonquilla simplex		86.0	784.0	90.0	839.0	24.0
Chionodoxa forbesii	Pink Giant	57.0	475.0	68.0	576.0	17.3
Chionodoxa sardensis		64.3	543.0	72.7	597.3	14.7
Anemone blanda	Blue Shades	66.0	541.5	75.0	652.5	12.0
Eranthis hyemalis		37.0	249.0	45.0	323.0	8.0
Iris danfordiae		45.0	323.0	45.0	323.0	8.0
Muscari neglectum		57.0	475.0	66.7	553.0	8.0
Anemone blanda	Pink Star	75.0	608.0	75.0	608.0	1.3
	LSD (0.05)†	7.5	75.3	7.6	78.1	23.7

† LSD = least significant difference values (α = 0.05) for comparing means within a column.

Table 7. Effects of various spring bulb entries on day of year (DOY) and growing degree day units (GDD) to first observed flowers, DOY and GDD to peak flower, and percentage of twenty-five planted bulbs that produced flowers in a raised bed (2016 data).

Scientific Name	Cultivar (if known)	First flower	First flower	Peak flower	Peak flower	bulbs w/ flowers
		DOY	GDD	DOY	GDD	%
Narcissus spp.	Rip Van Winkle	58.0	319.0	66.0	397.0	100.0
Muscari armeniacum		66.0	397.0	68.3	429.3	98.7
Crocus flavus	Golden Yellow	54.0	280.0	66.0	397.0	96.0
Crocus vernus	Flower Record	54.3	281.0	66.0	397.0	96.0
Narcissus spp.	Rijnveld's Early Sensation	54.0	280.0	66.0	397.0	96.0
Narcissus spp.	Tete-a-Tete	54.3	281.0	66.0	397.0	94.7
Muscari negelctum		58.0	319.0	68.3	429.3	93.3
Muscari aucheri	Mount Hood	68.3	429.3	70.7	461.7	90.7
Crocus chrysanthus	Cream Beauty	54.0	280.0	66.0	397.0	89.3
Crocus chrysanthus	Blue Pearl	54.0	280.0	58.0	319.0	88.0
Hyacinthus orientalis	Pink Pearl	66.0	397.0	70.7	461.7	88.0
Leucojum aestivum		70.7	461.7	73.0	494.0	88.0
Narcissus spp.	Baby Moon	101.0	838.0	101.0	838.0	88.0
Crocus tommasinianus	Ruby Giant	66.0	397.0	66.0	397.0	81.3
Crocus sieberi	Tricolor	54.0	280.0	55.0	283.0	78.7
Crocus vernus	Rememberence	62.0	358.0	66.0	397.0	72.0
Chionodoxa sardensis		66.0	397.0	73.0	494.0	70.7
Narcissus canaliculatus		68.3	429.3	70.7	461.7	70.7
Crocus olivieri balansae var.		54.3	281.0	58.3	320.0	69.3
Muscari spp.	Valerie Finnis	68.3	429.3	79.0	558.0	65.3
Chionodoxa forbesii	Pink Giant	66.0	397.0	73.0	494.0	57.3
Crocus isauvicus	Spring Beauty	66.0	397.0	66.0	397.0	57.3
Iris histrioides	Katherine Hodgkin	54.0	280.0	58.0	319.0	56.0
Narcissus jonquilla simplex		94.7	755.3	101.0	838.0	48.0
Iris danfordiae		54.0	280.0	54.0	280.0	25.3
Anemone blanda	Blue Shades	73.7	493.7	79.0	558.0	24.0
Eranthis hyemalis		62.0	358.0	70.7	461.7	16.0
Ipheion uniflorum		101.0	838.0	101.0	838.0	5.3
Ipheion uniflorum	Rolf Fiedler	77.5	542.0	77.5	542.0	4.0
Anemone blanda	Pink Star	82.0	590.0	82.0	590.0	1.3
	LSD (0.05)†	6.8	78.6	5.5	63.5	15.2

† LSD = least significant difference values (α = 0.05) for comparing means within a column.

Table 8. Effects of various spring bulb entries on day of year (DOY) and growing degree day units (GDD) to first observed flowers, DOY and GDD to peak flower, and percentage of twenty-five planted bulbs that produced flowers in a raised bed (2017 data).

Scientific Name	Cultivar (if known)	First flower	First flower	Peak flower	Peak flower	bulbs w/ flowers
		DOY	GDD	DOY	GDD	%
Leucojum aestivum		75.0	638.0	92.0	870.3	98.7
Ipheion uniflorum		50.7	398.0	87.0	793.3	85.3
Muscari spp.	Valerie Finnis	69.0	593.7	96.0	933.0	80.0
Narcissus canaliculatus		50.0	396.0	60.7	509.0	80.0
Crocus flavus	Golden Yellow	32.3	213.0	48.3	371.7	72.0
Narcissus spp.	Rip Van Winkle	52.3	422.3	66.7	553.3	62.7
Narcissus spp.	Baby Moon	84.7	765.7	92.0	870.3	62.7
Crocus isauvicus	Spring Beauty	37.3	255.7	54.7	448.7	56.0
Muscari armeniacum		58.3	482.7	87.0	793.3	56.0
Crocus tommasinianus	Ruby Giant	54.7	448.7	70.3	587.3	54.7
Narcissus spp.	Tete-a-Tete	60.7	493.0	70.3	587.3	52.0
Crocus chrysanthus	Cream Beauty	30.0	195.0	45.0	323.0	50.7
Muscari aucheri	Mount Hood	60.7	509.0	80.0	715.0	50.7
Ipheion uniflorum	Rolf Fiedler	65.3	559.7	84.7	765.7	44.0
Anemone blanda	Blue Shades	57.0	475.0	80.0	715.0	42.7
Crocus vernus	Flower Record	50.0	396.0	57.0	475.0	42.7
Crocus chrysanthus	Blue Pearl	32.3	213.0	46.7	347.3	34.7
Crocus vernus	Rememberence	46.7	347.3	50.0	396.0	34.7
Narcissus spp.	Rijnveld's Early Sensation	54.7	448.7	58.3	482.7	24.0
Narcissus jonquilla simplex		68.0	577.0	82.0	729.0	22.7
Chionodoxa sardensis		64.3	543.0	80.0	715.0	20.0
Muscari negelctum		44.0	322.7	75.0	638.0	20.0
Anemone blanda	Pink Star	68.0	577.0	78.5	668.5	10.7
Chionodoxa forbesii	Pink Giant	56.0	456.3	72.7	597.7	10.7
Iris histrioides	Katherine Hodgkin	50.7	398.0	50.7	398.0	6.7
Crocus olivieri balansae var.		25.3	170.3	30.0	200.7	5.3
Crocus sieberi	Tricolor	50.0	396.0	47.5	359.5	2.7
Eranthis hyemalis		41.0	286.0	41.0	286.0	2.7
Hyacinthus orientalis	Pink Pearl	53.5	435.5	53.5	435.5	2.7
Iris danfordiae		57.0	475.0	57.0	475.0	1.3
	LSD (0.05)†	9.9	102.0	10.2	126.5	31.9

† LSD = least significant difference values (α = 0.05) for comparing means within a column.

Table 9. Pollinator visits recorded on bulb species planted in a bermudagrass lawn.

Scientific Name	Cultivar (if known)	2016	2017		Total	
		----------- pollinator visits / min. -------------				
Crocus flavus	Golden Yellow	0.00	1.00	A[z]	1.00	A
Muscari	Valerie Finnis	0.67	0.00	B	0.67	AB
Muscari armeniacum		0.67	0.00	B	0.67	AB
Crocus chrysanthus	Blue Pearl	0.00	0.33	B	0.33	BC
Ipheion uniflorum	Rolf Fiedler	0.00	0.33	B	0.33	BC
Muscari aucheri	Mount Hood	0.33	0.00	B	0.33	BC
	P > F	0.107	0.005		0.083	
	LSD (0.05)	ns	0.37		0.58	

[z] Within each column, means sharing a letter are not statistically different according to Fisher's protected LSD test ($\alpha = 0.05$).

Table 10. Pollinator visits recorded on bulb species planted in a buffalograss lawn.

Scientific Name	Cultivar (if known)	2016		2017		Total	
		------------ pollinator visits / min. ---------------					
Muscari armeniacum		1.00	A[z]	0.67	AB	1.67	A
Crocus flavus	Golden Yellow	0.00	C	1.00	A	1.00	B
Crocus chrysanthus	Blue Pearl	0.00	C	0.67	AB	0.67	BC
Crocus chrysanthus	Cream Beauty	0.00	C	0.67	AB	0.67	BC
Muscari	Valerie Finnis	0.67	AB	0.00	C	0.67	BC
Crocus isauvicus	Spring Beauty	0.00	C	0.33	BC	0.33	CD
Crocus vernus	Rememberence	0.00	C	0.33	BC	0.33	CD
Hyacinthus orientalis	Pink Pearl	0.00	C	0.33	BC	0.33	CD
Ipheion uniflorum		0.00	C	0.33	BC	0.33	CD
Muscari aucheri	Mount Hood	0.00	C	0.33	BC	0.33	CD
Muscari neglectum		0.33	BC	0.00	C	0.33	CD
	P > F	0.0006		0.0011		<0.0001	
	LSD (0.05)	0.38		0.48		0.55	

[z] Within each column, means sharing a letter are not statistically different according to Fisher's protected LSD test (α = 0.05).

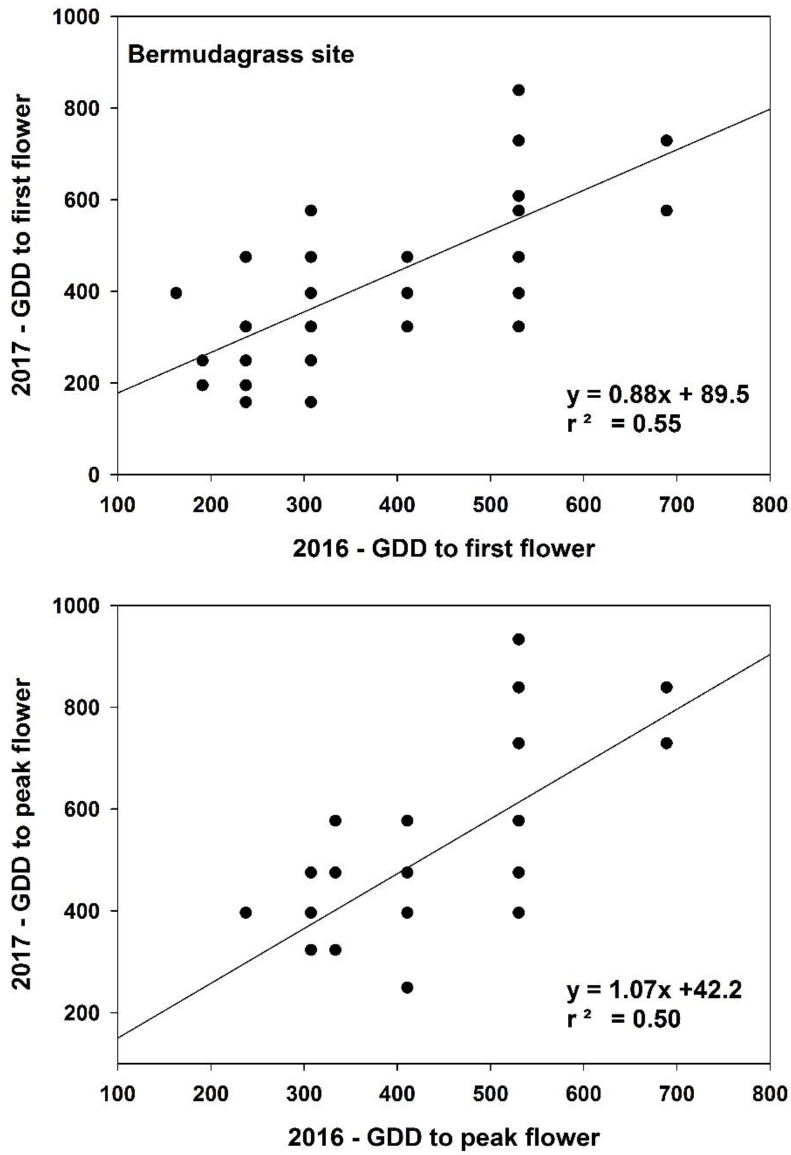
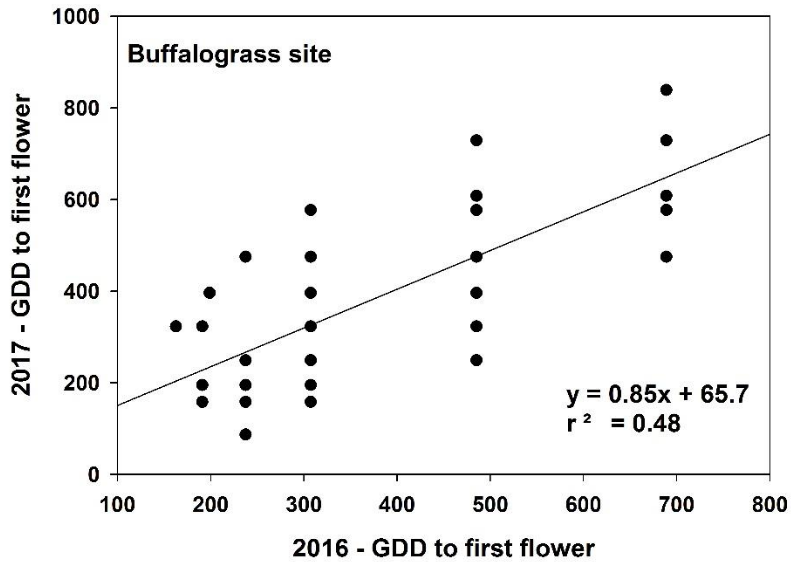


Figure 1. Regression analysis of GDD units required for first flower and peak flower in bermudagrass 2016-2017.



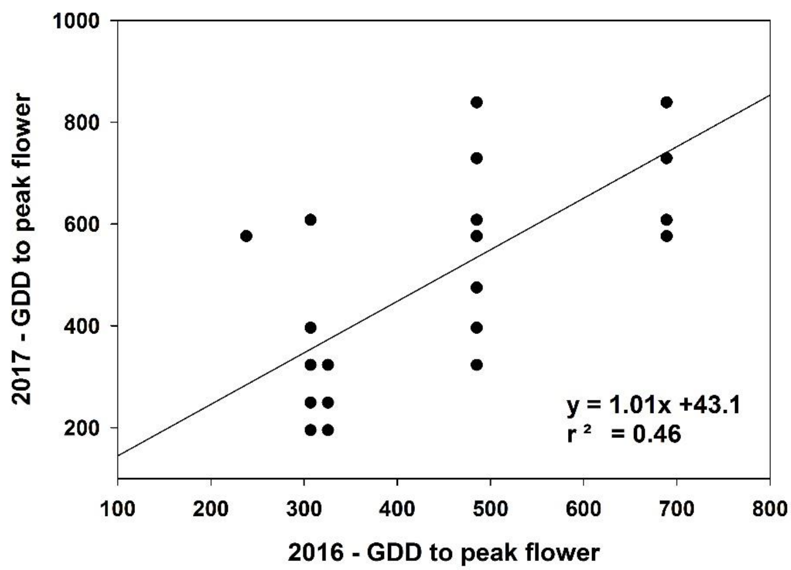


Figure 2. Regression analysis of GDD units required for first flower and peak flower in buffalograss 2016-2017.

Figure 3. Photo taken March 2016 of honey bee visiting *Muscari aucheri* ‘Mount Hood’ (photo by author).

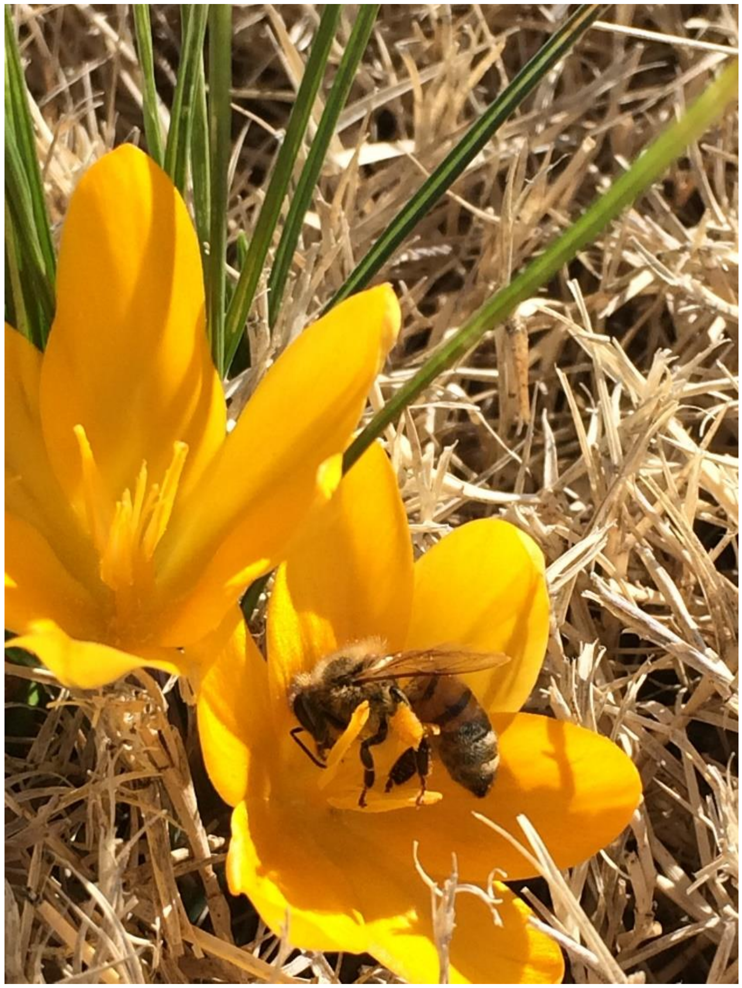


Figure 4. Photo taken January 2017 of honey bee visiting *Crocus flavus* ‘Golden Yellow’ (photo by author).

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Evaluation of Flowering, Perennial Plants in a Bermudagrass Lawn for Pollinator Forage

Abstract

Most pollinating insects require a season-long succession of floral resources to successfully fulfill life-cycle requirements. Incorporating herbaceous flowering perennial plants (forbs) into warm-season turfgrass may create a season-long sequence of flowers to support foraging pollinators. However, persistence of forbs in warm-season turfgrasses such as bermudagrass (*Cynodon* spp.) may be affected by the density and growth rate of the grass, and the cultural practices associated with turfgrass management. A study was conducted over two years (2016-2017) in Arkansas to evaluate eight species of forb for persistence in bermudagrass, and the ability of plants to produce floral resources for pollinating insects. The eight entries included *Bellis perennis*, *Claytonia virginica*, *Lotus corniculatus*, *Prunella vulgaris*, *Trifolium fragiferum* cv. Fresa, *Trifolium repens* cv. Durana and cv. Resolute, and *Trifolium subterraneum*. Entries were selected for reported mature height (<15cm) and varying flowering times. Entries were started from seed, and plugs were incorporated into an existing stand of 'Riviera' bermudagrass at the University of Arkansas Research and Experiment Center in April 2016. Assessments were taken on vegetative coverage, flower production, and pollinator interest. *Claytonia virginica* was the first entry to emerge and flower, from February-April in both years. *Prunella vulgaris* achieved 100% coverage in bermudagrass by 2017, exhibiting invasive tendencies. *Trifolium repens* persisted over the two year study period, achieving a balance with the bermudagrass and demonstrating the ability to produce flowers from April-July in both years. *Trifolium fragiferum* cv. Fresa persisted over two growing seasons, and although it did not bloom in 2016, it flowered in July 2017. *Bellis perennis*, *Lotus corniculatus*, and *Trifolium subterraneum* did not persist in bermudagrass. Pollinators were observed to be foraging on all persistent forbs. Entries preferred

by pollinating insects included *Trifolium repens* cvs. Durana and Resolute, *Prunella vulgaris*, and *Trifolium fragiferum* cv. Fresa. Results of this study established a succession of flowering times for five entries, from February through August, and combinations of forbs that can persist in bermudagrass and provide nutrition to pollinating insects. The benefit to pollinators confirms another potential ecosystem service of turfgrass in both urban and rural environments.

Introduction

Pollination

Thirty-five percent of global food crop production depends on pollinators (Blacquiere et al., 2012), with honey bees being the most prominent and economically important group of pollinating insects worldwide (McGregor, 1976). Globally, 87 of the leading 115 food crops rely on insect or animal pollinators (Klein et al., 2006). In 2009, Gallai et al. put the total economic value of pollination worldwide at €153 billion ($178 billion US$ in current exchanges). Pollination is simply the transfer of pollen from the stamen, or male portion of a flower, to the stigma, or female portion of a flower (Von Frische, 1954), resulting in seed and fruit set. The plant/pollinator relationship is mutually beneficial, as plants supply nourishment, in the form of pollen and nectar, to the insect, while the insect ensures reproduction and survival in plants via seed and fruit set (Ollerton et al., 2011). Human and animal populations directly benefit from healthy plant/pollinator affiliations, for the simple fact that the result is food (nutrition). Of over 352,000 species of angiosperms, 85% require some form of insect or animal pollination (Ollerton et al., 2011). Examples of biotic pollinators include bees, wasps, and ants (all members of Hymenoptera), butterflies and moths (Lepidoptera), flies (Diptera), beetles (Coleptera), birds (Apodiformes), and some mammals (Potts et al., 2016). In a society which relies upon agriculture to support healthy living standards, pollination services are critical to ensure the continued ability of the world to feed its population.

Pollinators

Humankind needs pollinators and pollinating insects need flowers for nutrition (Michener, 1974). Bees are the predominant and most economically important group of pollinators in most geographical regions (Kremen et al., 2007). The diet of all bee species consists exclusively of pollen and nectar collected from flowers (Michener, 1974). Most bees require a mixture of pollen from a variety of floral resources to ensure a balanced and diverse diet (Brodschneider and Crailsheim, 2010; Wackers and van Rijn, 2012). Bee generalists, who demonstrate "polylectic" behavior, collect pollen from a variety of unrelated sources (Ritchie et al., 2016). Abundance of floral resources in the landscape may strongly influence the pollination services provided by bumble bees (Williams et al., 2012). However, some pollinating insects exhibit "oligolecty", or floral specificity and harvest pollen only on a limited number of plant taxa (Ritchie et al., 2016; Robertson, 1925). For specialists, loss of specific nutrition sources has dire consequences for species survival, and poor nutrition due to lack of floral resources has caused the decline and extinction of some pollinator specialists (Murray et al., 2009). Whether a generalist or specialist, a commonality between species is the requirement for flowers to survive.

Honey bees are polylectic. It has been demonstrated that honey bees fed with pollen of various plants have healthier immune systems compared to bees that were pastured only on monocultures (Bekic et al., 2014). Polyfloral diets have been found to enhance immune functions and aid in better in-hive antiseptic protection for honey bees (Alaux et al., 2010), which in turn creates a more pathogen resistant environment inside the hive. Severe declines in bee diversity, abundance, and ranges are concurrent with declines in bee-pollinated flowering plants (Murray et al., 2009). Reduction in the abundance and diversity of flowering plants needed to ensure good nutrition throughout a season contribute, as well (Alaux et al., 2010). According to Gallai et al., 2009, mounting evidence of pollinator declines signal significant societal consequences, most notably the vulnerability of global agricultural output.

Pollinator populations have dropped in recent decades for reasons including habitat fragmentation and loss (Kremen et al. 2007; Murray et al., 2009), the use of monocultures and pesticides (Goulson et al., 2015), poor nutrition (Alaux et al. 2010), the introduction of exotic pests and diseases (Goulson, et al., 2015), Colony Collapse Disorder (CCD) in honey bees (Van Engelsdorp et al., 2009), and climate change (Biesmeijer et al., 2006; Goulson et al., 2008). Each might be considered a stand-alone threat to pollinator health. Combined, they represent a massive hurdle to insect survival.

Many times the numeric value put on pollination services is directly correlated with the European honey bee (*Apis mellifera*), an imported and highly social species (Khoury et al., 2011). In the United States, honey bees are responsible for pollinating approximately 100 horticultural crops. However, the importance of wild pollinators cannot be overlooked. For many agricultural outputs, wild bees are better pollinators compared to honey bees (Burkle et al., 2013; Garibaldi et al., 2013). The beef and dairy industry rely on wild pollinators for seed production in numerous livestock forages such as alfalfa (*Medicago sativa*), buckwheat (*Fagopyrum esculentum*), and clover (*Trifolium* spp.) (USDA, 2009). Historically, almond (*Prunus dulcis*) farmers in California utilized pollination services from wild, unmanaged bees (Watanabe, 1994). However, decline of wild populations created an industry which moves honey bee hives across the U.S., termed "migratory beekeeping", to fill pollination service requirements in crops as diverse as almond in California, cranberry (*Vaccinium* spp.) in Maine, and citrus (*Citrus* spp.) in Florida. Although it seems that honey bee hives subjected to these practices might benefit from guaranteed floral resources for weeks at a time, gluts of flowers of one kind offer a monotonous and nutritionally deficient diet. Additionally, these agricultural systems might cause an exposure to pesticides used to control broadleaf perennials, pests, and diseases within the cropping systems, to the detriment of the pollinating insects.

In contrast to honey bees, many native bees are solitary, and fulfill their life cycle as a single individual. They dwell in diverse locations such as cavities underground, hollow-stemmed twigs, burrows in the soil, or even abandoned snail shells (Goulson et al., 2015; Shepherd et al., 2003). Bumble bees and some stingless bees are the exception, as they live in colonies a few hundred strong, exhibiting a primitive social structure (Goulson, 2003). What most bees and other pollinating insects have in common is a need for a diversity and succession of floral resources to be available throughout seasons when pollinators are active. Floral resources provide nutrition while enhancing pollinator health (Goulson et al., 2015; Wackers and Van Rijn, 2012). Floral resources can be native and non-native flowering plants, either ornamental or weedy species. However, not all flowering plants are suitable selections for pollinator nutrition. Some flowers, although abundant, do not produce pollen and/or nectar. Maintaining a diversity of the correct season-long floral resources is essential to supporting a diversity of pollinating insects (Williams et al., 2015). Baseline habitat guidelines encourage the inclusion of at least three plants that flower at any given time during spring, summer, and/or fall (Vaughn and Skinner, 2015). Clumping single species together, and placing foraging habitat adjacent to nesting sites will also attract pollinating insects (Spivak et al., 2011). Significant expanses of managed turfgrasses, such as roadsides, cemeteries, and lawns, represent areas of land that might be designed and managed to feed pollinating insects (Hopwood, 2008; Ries et al., 2001).

Turfgrass

Turfgrass is often viewed as a monoculture. Land covered by turfgrass in the United States is estimated to be more than sixteen million hectares (Milesi et al., 2005). Historically, seed mixtures for lawns included clover and other legumes, primarily added to enhance nitrogen availability in the turfgrass (Tyson, 1941). With advances in chemical herbicides and fertilizers in the mid-20th century, lawn mixtures that included legumes lost popularity and a more uniform aesthetic appearance became desirable. Home lawns often contain naturally occurring flowering perennials (forbs), and these nutrition sources are under-appreciated resources for pollinating insects (Larson et al., 2014). However, due to increased herbicide use and changing landscape preferences, many forbs have been eliminated from the turfgrass ecosystem, consequently eliminating the landscape of floral resources for pollinators (Larson et al., 2014).

Turfgrass provides many ecosystem services in the urban landscape, including carbon sequestration, oxygen production, water filtration, erosion and dust control, aesthetic and recreational, and reduction of heat island effects (Beard and Green, 1994). Turfgrass systems might also create opportunities to attract and protect pollinators in the landscape, by incorporating plants, such as leguminous and other species previously eradicated, to create a succession of flowers throughout the growing season. Such plants must be able to compete with turfgrasses by demonstrating traits that allow them to flower and persist under mow pressure, low fertility, and little to no irrigation. Turfgrasses are typically classified as either warm-season or cool-season plants, but many areas of the world are considered “transition zones”, where both types will occur. Bermudagrass (*Cynodon* spp.), a warm-season turfgrass, is the most commonly used lawn grass in Arkansas (Boyd, 2016). Bermudagrass grows rapidly by rhizomes and stolons, and demonstrates a dense and spreading growth habit. Recent studies have investigated introduction of white clover (*Trifolium repens*) into bermudagrass turf. This work evaluated various establishment methods (McCurdy et al., 2013a), the contribution of nitrogen from clover to the surrounding turf (McCurdy et al., 2013b; McCurdy et al., 2014), and the potential of white clovers as pollinator forage (Larson et al., 2014). However, limited work has been done in assessing persistence of clovers and other forbs in bermudagrass, to determine pollinator preference for flowers.

This study sought to identify herbaceous flowering perennial plants, including legumes and other forbs, which produced a season-long succession of floral resources for pollinating insects. A significant consideration was the selection of plants that could coexist and persist in the competitive warm-season turfgrasses. The objectives of this study were as follows:

- Identify spring, summer, and fall flowering plants that will persist in warm-season turfgrass
- Determine flowering periods of the various flowering perennials
- Determine pollinator preference for successful flowering perennials

It was our goal to identify and test forbs to create a useful plant list for home, land, or business owners who are interested in incorporating pollinator friendly herbaceous flowering perennials into their warm-season lawn.

Materials and Methods

A field study was established at the University of Arkansas Agricultural Research and Experiment Center located in Fayetteville, AR (36:05:46.8 N, 94:10:28.5 W NAD83, 394 m NAVD88). The soil at the site was a Captina silt loam (fine-silty, siliceous, active, mesic Typic Fragidults) with an average pH of 6.2. The area chosen for the study was a full-sun site established in 2005 to 'Riviera' bermudagrass. The site was chosen to test the competitive habits of the forbs, as bermudagrass is considered a dense, competitive turfgrass, and is a highly utilized warm-season turfgrass in Arkansas (Boyd, 2016).

Plants were chosen based on reported mature height at bloom and their bloom time. In general, plants were chosen to have a mature height of <15 cm and were selected to exhibit flowering times throughout spring, summer, and fall, among all species. Eight species and/or cultivars of forbs were selected and tested in this trial (Table 1), and were purchased from seven distributors: Eden Brothers, Asheville NC; Horizon Herbs LLC, Williams OR; Monticello, Charlottesville VA; Mountain Rose Herbs, Eugene OR; Outsidepride.com, Independence OR; Prairie Moon Nursery, Winona MN; and Strictly Medicinal LLC, Williams OR. 'Durana' and 'Resolute' white clover seeds were provided by Dr. Ali Missaoui, legume breeder at the University of Georgia. The two species of *Trifolium repens* were intermediate types, or crosses that were developed to give high yields and persist under grazing pressure (Olsen and Clark, 2016), and were chosen to withstand cultural practices of a low-maintenance bermudagrass lawn.

It was assumed that attempts to sow seed directly into bermudagrass would most certainly have experienced some level of failure. As such, selected plants were started from seeds in the greenhouse. Seeds were sown into planting trays containing Miracle Grow Potting Mix, at the Rosen Alternative Pest Center (APC) greenhouse facilities in Fayetteville, in February 2016. Plugs were transplanted into 10 cm pots in March 2016 and transferred to an unheated greenhouse on 11 April 2016 to harden off and prepare for establishment into the field. Entries were transplanted into the field on 14 April 2016.

The experimental design was a single-factor (entry), randomized complete block design with four replicates of each entry. Although the total plot area for each treatment was 0.8 m^2, nine plugs were planted in a 0.9 x 0.9 m area in the center of the plot, with buffers between plots. A 3 x 3 template was constructed for each plot and was used to mark planting sites, by spraying paint through pre-cut holes on 30 cm spacing. Planting holes were made by using a 10 cm diameter turfgrass cup cutter and potted plugs were placed into the holes and covered with loose soil. Seven entries were started from seed and incorporated into the field study from the greenhouse plugs. However, *Claytonia virginica*, a corm, was planted directly in the field. Holes were made in the soil with a 5 cm diameter plugger and flowering corms were placed directly into the holes and covered with loose soil. Mowing was initiated in the third week of May 2016, to give plants the best opportunity for early establishment. Mowing was initiated the second week of May 2017, after bermudagrass broke dormancy and new growth was evident. Mowing height of the bermudagrass was 7.5 cm and was timed to every other week during the growing season, to simulate a low-maintenance lawn. The turf received 7.5 g N/m^2 (46-0-0, Thrive Branded Urea, Mears Fertilizer, Inc. El Dorado, KS), applied in July of each year. Chemical weed control was not utilized, with individual plots and alleyways being hand-weeded when visual inspection indicated excessive growth of undesirable species, i.e. when weedy species began interfering with or encroaching upon study entries. Supplemental irrigation was applied from April-June 2016, upon incorporation of plugs into the study site, and was withheld during the remainder of the study.

Data collection was primarily focused on establishment, performance and persistence of forbs over the two-year period. Each treatment was evaluated for vegetative coverage per plot, number of flowers per plot, and pollinator activity on flowers, all averaged by month. Vegetative coverage was measured twice monthly, by placing a 1 x 1 m grid with intersects spaced at 10 cm intervals, over each plot and counting the number of line intersects where vegetative growth of the entry was present. Flower counts were measured twice monthly by randomly tossing a 30 x 30 cm^2 wooden template into each plot two times, counting flowers within the template, and calculating flowers per m^2. Pollinator activity counts were taken four times/weekly, in one minute increments per plot, when pollinating insects were observed to be actively foraging within the study site. Pollinators that landed on flowers and foraged were counted, while pollinators that did not forage were not counted. Foraging was defined as visible feeding upon pollen or nectar in the flower. Pollinators were broadly characterized as honey bees, bumble bees, native bees (all members of Hymenoptera), butterflies (Lepidoptera), or “other”, which included ants and wasps (Hymenoptera), beetles (Coleoptera), flies and hoverflies (Diptera) and unidentifiable insects.

Vegetative cover, flower counts and pollinator visits were analyzed in a repeated measures analysis of variance model in PROC MIXED (SAS v. 9.4, SAS Institute, Inc., Cary, NC) where month was included as the time in the analysis.

Results and Discussion

For vegetative cover, flower counts, and pollinator visits, the main effects of entry and month were statistically significant, as was the entry x month interaction (Table 2). As such, all data are presented as the entry x month interaction.

Vegetative coverage

Spring beauty *(Claytonia virginica)* was already flowering when incorporated into the study site in April 2016. Spring beauty foliage has less aggressive spreading habits than other entries, and less foliage was identified using the grid counts. English daisy (*Bellis perennis)* was also flowering when transplanted into the study site in April 2016. English daisy attained up to 54% vegetative coverage in 2016, but only a single plant emerged in 2017, prohibiting further vegetative coverage assessment. Self-heal (*Prunella vulgaris*), strawberry clover (*Trifolium fragiferum* cv. Fresa), and white clover (*Trifolium repens* cvs. Durana and Resolute) established quickly in the bermudagrass turf and exhibited varying levels of persistence. Self-heal had over 60% vegetative coverage in bermudagrass at the end of the 2016 growing season and attained 100% coverage by July 2017, even demonstrating invasive tendencies (Figure 1). Strawberry clover had approximately 40% vegetative coverage at the end of the first season and maintained 30% vegetative coverage from April-July 2017 (Figure 1). However, vegetative cover of this entry dropped significantly (<10%) by August 2017. Both white clover entries had up to 80% vegetative coverage at the end of 2016, and close to 100% vegetative coverage beginning in April 2017. However, the white clovers became more balanced with the bermudagrass turf by the end of 2017, with approximately 50% vegetative coverage on 1 August 2017 (Figure 1). Birds-foot trefoil (*Lotus corniculatus*) had approximately 20% vegetative coverage in June/July 2016 but dropped to <5% vegetative coverage by the end of the first season, and struggled to persist throughout 2017 (Figure 1). Although subterranean clover (*Trifolium subterraneum*) was visible through June 2016, it was undetectable in July 2016 did not emerge in 2017 (data not shown).

Flower counts

Spring beauty initiated flowering in February of 2016 and 2017. Although individual plants which flowered were noted, flower counts were not taken due to an oversight by the author. However, it was observed that spring beauty persisted and flowered in bermudagrass over at least two seasons. Spring beauty continued to flower through the end of April in both years. English daisy was also flowering when incorporated into the study site in April 2016. However, only one flower was observed upon a single plant that emerged in 2017 and no further flower count data were collected. Self-heal initiated flowering in June 2016 and 2017, with maximum flower counts observed from July-August of both years (Figure 2). White clover (cvs. Durana and Resolute) initiated flowering in March in both 2016 and 2017. Both cultivars of white clover produced maximum flowers from June-July of both years (Figure 2). It is important to note that self-heal and both cultivars of white clover continued to produce abundant flowers through August 2017 and self-heal continued to produce some flowers into October of 2016-

2017 (data not shown). Although strawberry clover did not flower in 2016, it initiated flowering in May 2017, and maximum flower counts were observed from June-July 2017 (Figure 2). Birds-foot trefoil initiated flowering in June 2016 and 2017, with highest flower counts observed in early July of both years (Figure 2). Subterranean clover did not flower in 2016 or 2017 (data not shown).

Pollinator visits

Pollinator activity was observed at various times of the day throughout the study period. As would be expected, pollinator visits were closely associated with flower counts, with both cultivars of white clover receiving greater pollinator activity in June and July, while self-heal received a higher number of pollinator visits in late July/early August (Figure 3). Although pollinator activity is well-documented on spring beauty (Parker et al., 2016), it was not observed on spring beauty in this study. Pollinators were observed on English daisy from April-June 2016 (Figure 4). However, because of lack of persistence by English daisy in bermudagrass in this study, insect activity was not observed in 2017. Strawberry clover did not attract pollinating insects in 2016. However, in 2017, strawberry clover flowered and attracted pollinating insects beginning 1 July and spiking by the end of the month (Figure 4). Birds-foot trefoil demonstrated attractiveness to pollinating insects in early July of each year (Figure 4). Subterranean clover did not produce flowers and did not attract pollinating insects. A wide range of pollinators were observed on the forbs, including honey bees, bumble bees and other native bees, butterflies, ants, wasps, and flies (Table 3).

In summary, white clover entries performed well and, by 2017, stabilized at approximately 50% coverage in bermudagrass. Generally, clovers (*Trifolium* spp.) are known to be adapted to a wide range of climatic and soil conditions (Olsen and Smith, 2016) and, as mentioned earlier, clover seed was historically included in turfgrass mixtures primarily to add nitrogen to the turfgrass ecosystem (Tyson, 1941). Today, clover inclusion within maintained turfgrass is a proposed means of increasing turfgrass sustainability by reducing fertilizer inputs and enhancing biodiversity (McCurdy et al., 2013b). White clover is a low growing, perennial legume (Olsen and Smith, 2016), which can flower and produce seed at mowing heights as low as 6 mm (Watschke et al., 1995). Scientists from Auburn University, Mississippi State University, and the University of Kentucky, have conducted studies incorporating white clover into lawns, to supplement the N requirements of warm-season grass swards, and potentially increase pollinator habitat (Larson et al., 2014; McCurdy et al., 2014).

In the present study, self-heal exhibited close to 100% coverage in bermudagrass by 2017, and may be too invasive to consider in a lawn in this region. The University of Minnesota recently established that white clover, self-heal, and wild thyme (*Thymus serpyllum*) can persist in hard fescue (*Festuca brevipila*), a cool-season grass, to supply pollinators with nutrition and forage sources in home lawns, or low-maintenance turf areas such as roadsides or cemeteries (Lane, 2016). The current study confirms that self-heal may also be a potential source of pollinator forage in warm-season lawns such as bermudagrass.

Leguminous species such as red clover (*Trifolium pratense*), strawberry clover, subterranean clover and white clover, not only add nitrogen to the turf (McCurdy et al., 2013b), but are low-maintenance, sustainable solutions as food sources for pollinators (Larson et al. 2014; Cook, 2005). Birds-foot trefoil, a bee-pollinated leguminous species known to thrive in poor soils in meadows and along highways (Cussans et al., 2010), might also be used to attract pollinators at restoration sites, although it was unable to compete with bermudgrass in the present study. Non-leguminous herbaceous perennials, like English daisy, spring beauty, and self-heal have also proven to be reliable, pollinator-friendly lawn options (Burkle et al., 2013; Cook, 2005; Lane, 2016). Common spring lawn weeds such as purple deadnettle (*Lamium purpureum*) and henbit (*Lamium amplexicaule*) are also used by pollinators in early spring (Brown, 2016; Steinkraus, 2010), and both support honey bees and many species of native bees. Thistle (*Cirsium* spp.) is considered a scourge by farmers but is an important component of pasture and urban flower meadows because it is a valuable source of seeds for birds and other wildlife, plus pollen and nectar for bees and other pollinating insects (Hicks et al., 2016). Generally, although the previously mentioned plants are most often considered weedy species, each is a potential source for pollinator nutrition and might be adapted or transitioned into lawns, roadsides, cemeteries, parks, and/or golf course out of play areas to provide pollinator nutrition and habitat.

A consideration when finalizing this study was that turfgrass professionals might be hesitant to add clovers or other forbs to grassy areas as they could become invasive, causing harm to the turfgrass, and creating a need for additional pesticide application. While plots were cultivated as low-maintenance lawn areas, with minimal mowing, irrigation, and fertilization, addition of some forbs to lawn sites did not harm the turf. In fact, white clovers achieved a balance with bermudagrass, while observed greening of the surrounding turf suggests that the bermudagrass was likely receiving nitrogen from the clover, as documented by McCurdy et al., 2013b.

Conclusions

Pollination services provide sustenance for a growing human population. However, habitat loss and other anthropogenic factors are straining pollinator populations. Pollinating insects require appropriate season-long floral resources to support healthy life cycles. Establishing habitats and resources to encourage pollinator presence, on a small or large scale, is essential pollinator survival. While this study provides proof that some forbs can persist in equilibrium with an aggressive warm-season turfgrass, additional studies are needed to evaluate alternative herbaceous flowering perennials which might support pollinators and beneficial insects. While nitrogen fixation and pollinator forage are two benefits of adding legumes and other forbs to turfgrass, additional considerations might be which plants serve as habitat for beneficial insects that prey on pests (such as mealybug destroyer and lady beetles), and which forbs add general biodiversity to the surrounding area.

Eight species of herbaceous flowering perennial plants were tested over a 2-year period in bermudagrass in Northwest Arkansas. This study confirms that forbs will persist in bermudagrass, while producing a season-long succession of floral resources for pollinating insects. The benefit to pollinators confirms another potential ecosystem service of lawns in both urban and rural environments. Further research is needed to investigate alternative establishment methods into warm-season turfgrass, such as seeding rates of various forbs when plug production is prohibited. While bermudagrass is the most commonly used turfgrass in Arkansas, other warm-season grasses that might be tested for persistence of forbs include *Zoysia*, *Eremochloa*, *Stenotaphrum*, and *Buchloe* spp. Although our findings are indicative of the transition zone and an associated warm-season turfgrass, trial sites should be expanded to other geographic regions and include cool-season grasses such as *Poa*, *Festuca*, or *Lolium* spp. This would be a logical avenue for future research, since cool-season lawns occupy most temperate climates of the world.

Table 1. Species and/or cultivars of flowering plants established from plugs into a bermudagrass lawn.

Scientific name	Cultivar (if known)	Common name
Bellis perennis		English daisy
Claytonia virginica		Spring beauty
Lotus corniculatus		Birds-foot trefoil
Prunella vulgaris		Self-heal
Trifolium fragiferum	Fresa	Strawberry clover
Trifolium repens	Durana	White clover or Ladino clover
Trifolium repens	Resolute	White clover or Ladino clover
Trifolium subterraneum		Subterranean clover

Table 2. Analysis of variance demonstrating statistical significance in main effects of entry and month, and entry * month interaction.

Effect	DF	Vegetative Cover	Flowers	Pollinator visits
			Pr > F	
Rep	3	0.328	0.604	0.586
Entry	7	<.0001	<.0001	<.0001
Month	8	<.0001	<.0001	<.0001
Entry*Month	56	<.0001	<.0001	<.0001

Table 3. Pollinator diversity on herbaceous perennials in bermudagrass.

Entry	Honey bee	Bumble bee	Native bee	Butterfly	Other*
	--- number of pollinator visits documented for various entries -----				
Birds-foot trefoil	0	0	0	1	5
English daisy	0	0	4	0	0
Self-Heal	4	4	0	2	0
Spring Beauty	0	0	0	0	0
Strawberry clover	0	0	0	0	0
Subterranean clover	0	0	0	0	0
White clover - Durana	10	14	0	4	2
White clover - Resolute	14	19	1	12	3

*Other includes ants, wasps, flies, hummingbirds

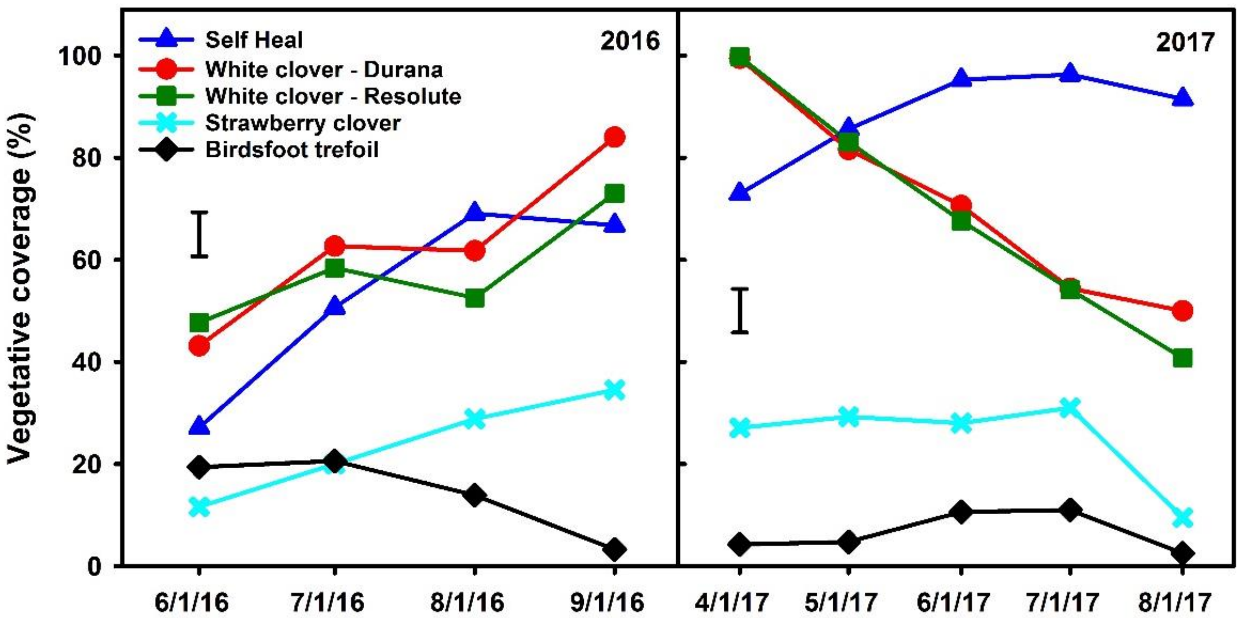

Figure 1. Vegetative coverage of five herbaceous perennials in bermudagrass. Error bars indicate Least Significant Difference (P=0.05) for comparing means.

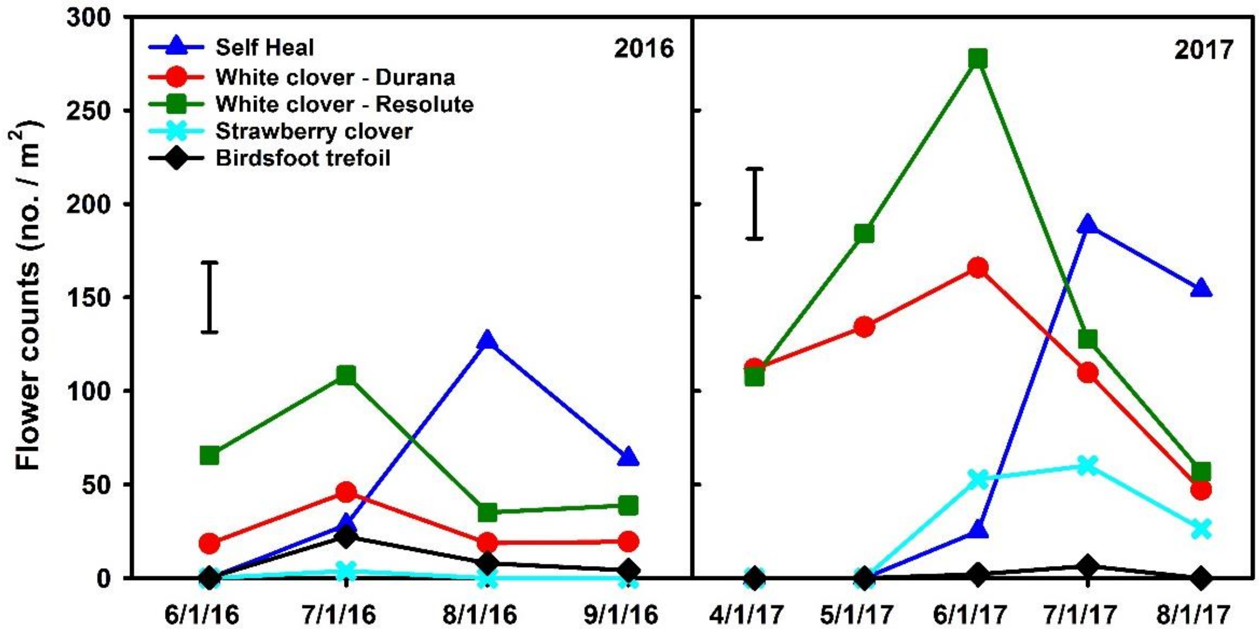

Figure 2. Flower counts of five herbaceous perennials in bermudagrass. Error bars indicate Least Significant Difference (P=0.05) for comparing means.

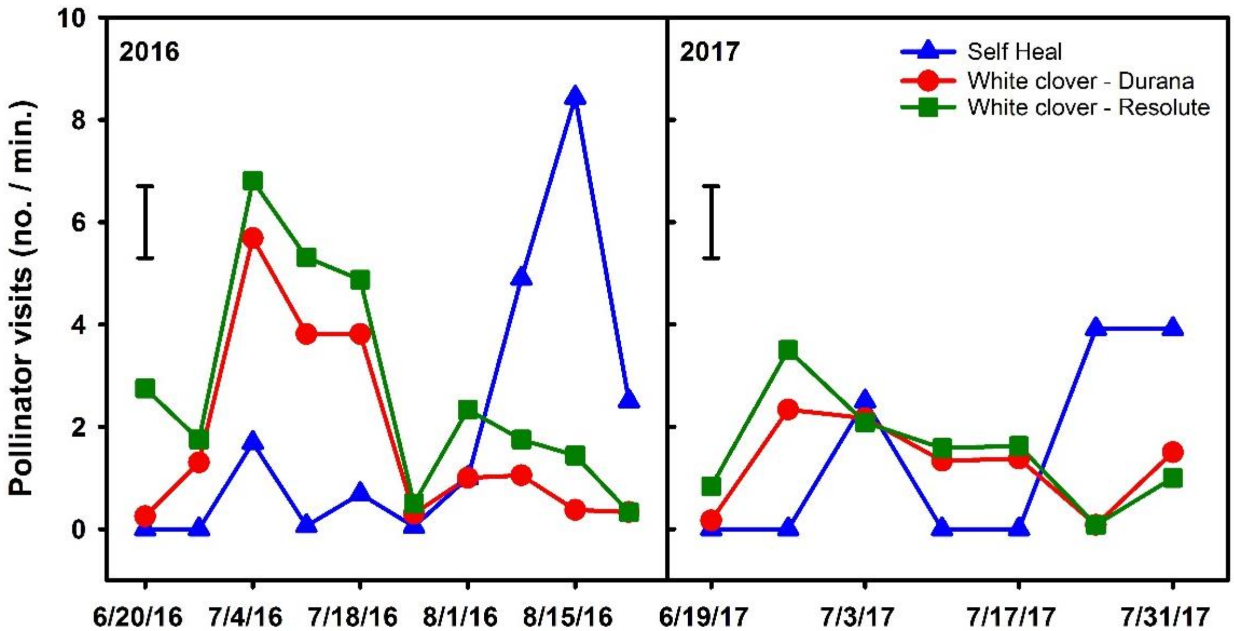

Figure 3. Pollinator visits on three herbaceous perennials in bermudagrass. Error bars indicate Least Significant Difference (P=0.05) for comparing means.

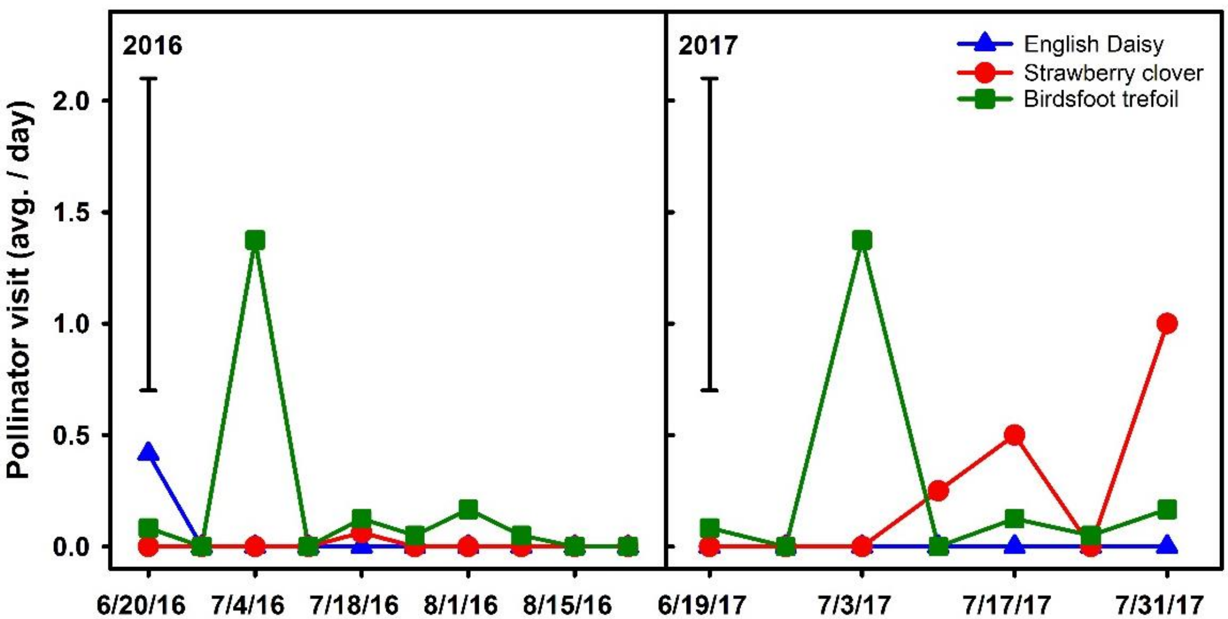

Figure 4. Pollinator visits on three herbaceous perennials in bermudagrass. Error bars indicate Least Significant Difference (P=0.05) for comparing means.

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Planting Methods for Flowering Bulbs in Warm-Season Turfgrass

Abstract

Establishment of flowering bulbs in warm-season turfgrasses such as bermudagrass (*Cynodon* spp.) may be affected by the competitive nature of the turf. A study was conducted over two years (2016-2017) in Arkansas to evaluate three planting methods for establishing early-spring bulbs in bermudagrass [*Cynodon dactylon* (L.) Pers.; cv. Riviera]. Bulbs included *Crocus tommasinianus* 'Ruby Giant', *Muscari armeniacum*, and *Narcissus* 'Rijnveld's Early Sensation'. Three planting methods were tested including: 1) traditional planting, which consisted of a hole augured directly into existing sod, with bulbs being placed in the hole and covered with loose soil; 2) sod removal, where sod was removed, bulbs were directly laid onto bare soil, and sod returned; and 3) new sod installation, where sod was removed, the soil underneath tilled to a depth of 7.6 cm to simulate a site to be planted with new sod, bulbs were placed on the tilled soil, and sod returned. Bulb emergence and flowering were monitored in the springs of 2016 and 2017. Establishment with the traditional method was best for first season emergence and flowering. However, data from the second season indicated that bulb persistence, emergence and flowering were not affected by any of the three planting methods. These results suggest that bulbs can be established in lawns using various techniques with similar success. This information could be of benefit to companies which supply and install warm-season turfgrass sod, either in existing or new construction situations.

Introduction

Bulbs

Flowering bulbs are an important global commodity and Europe, the US Pacific Northwest, Japan, and Africa have climates that support a vast bulb industry (Bryan, 2002). Flowering bulbs are defined as “geophytes”, derived from the Greek, geo – earth and phyton – plant (Raunkiaer, 1934). Ornamental geophyte are plant species that survive not only by seed but also by specialized underground storage organs (De Hertogh and Le Nard, 1993). Flowering bulbs have been used since ancient times for their medicinal and curative properties, and as sources of human nutrition (Bryan, 2002; Hessayon, 1996). *Lilium* spp., *Tulipa* spp., *Iris* spp., and *Crocus* spp. are depicted on pottery, palace walls, and thrones from Crete and Egypt as far back as 2200 B.C. (Bryan, 2002).

Botanically, flowering bulbs consist of leaves or a stem altered or adapted for storage (Chrungoo et al., 1983; Hessayon, 1996). Food reserves, nutrients, and moisture are stored in the underground repository and are an important component of survival (De Hertogh and Le Nard, 1993). Bulbs exist in various forms and typically demonstrate a short aboveground growth and bloom period (Khodorova and Boitel-Conti, 2013) that can occur throughout the season (Hessayon, 1996; Rees, 1992). The bulb is the underground nutrient storage structure from which the plant emerges and flowers, before returning to an underground, dormant state.

Many plant species are generically described as bulbs, when in fact their storage structures may be more appropriately characterized as corms, rhizomes or tubers (Hessayon, 1996). True bulbs consist of layers of modified leaves and contain an embryo flower which is easily visible when the bulb is cut open through its center (Weston, 1931). A true bulb appears scaly and exhibits a basal plate from which roots extend. Examples of true bulbs include

Hyacinthus, *Muscari*, and *Narcissus* spp. (De Hertogh and Le Nard, 1993). A corm, although a solid structure, exhibits a nutrient holding body that is a stem base (Hessayon, 1996) that has a basal plate with distinct nodes and internodes (De Hertogh and Le Nard, 1993). Examples of corms are *Crocus* and *Gladiolus* spp. Tubers and rhizomes, also modified stems, do not demonstrate basal plates but have eyes or buds on the surface or neck of the stem (Weston, 1931). Examples of tubers and rhizomes are *Anemone*, *Eranthis*, and *Iris* spp. (De Hertogh and Le Nard, 1993). Although there are various botanical forms that are considered bulbs, the common feature of all these species is a dormancy period, or state of suspended growth (Bryan, 2002).

Dormancy, a strategy of higher plants to survive adverse conditions by pausing growth and development (Soppe and Leonie, 2016), occurs at different times of the year for various bulb species. Early-spring flowering bulbs will typically bloom from late winter to early summer, depending on the species (Dana et al., 2001). As bulb foliage senesces, nutrients in the foliage are translocated into the bulb, to be stored throughout the dormancy period (Chrungoo et al., 1983). Temperature fluctuations or changes in soil moisture trigger conversion from bulb to flower, and the cycle continues.

Turfgrass

Some flowering bulbs will naturalize in grassy areas and can often be observed in unmanaged meadows and pastures (Bryan, 2002; Leeds, 2000; Phillips and Rix, 1989). In the United States, there are over sixteen million hectares of managed turfgrass, which include lawns, cemeteries, parks, and road sides (Beard and Green, 1994; Milesi et al., 2005). These spaces include warm- and cool-season turfgrasses. Warm-season turfgrass such as bermudagrass (*Cynodon* spp.) experience a lengthy dormancy period which overlaps with the flowering period of early-spring bulbs (Mirabile et al., 2016). Low temperatures induce turfgrass dormancy and result in a loss of green color though out the dormant period (Patton, 2012). Adding color to these situations, without disrupting the growth cycles of turfgrass, might be accomplished through incorporation of early-spring flowering bulbs. These bulbs can emerge, flower, and senesce before the turfgrass breaks dormancy. In theory, their life cycle will not interfere with the life cycle of the turfgrass; mowing and droughty conditions should not affect the bulbs, and the bulb growth cycles should not disrupt warm-season turfgrass systems. A sequence might be achieved which allows early color in the landscape without diminishing the function and beauty of the lawn.

A literature review revealed that little work had been done in early-spring flowering bulbs and whether bulbs can persist in competitive warm-season turfgrasses. However, one study concluded that bulbs will persist in *Zoysia japonica* 'Zenith' (Richardson et al., 2015), a warm-season turfgrass that is a low, slow-growing, sod-forming grass that makes a dense, wear-resistant lawn (Patton and Boyd, 2008). That study also found that pre-emergent herbicide applications have no effect on bulb emergence and flowering (Richardson et al., 2015). A second study established that three bulb species were able to persist in a bermudagrass (*Cynodon dactlyon* x *Cynodon transvaalensis* cv. 'Tifway 419') turf, adding color and biodiversity to the dormant turfgrass, while reducing the number of mowing events (Mirabile et al., 2016). Some early-season bulbs, such as *Crocus* spp. and *Muscari* spp., provide foraging honey bees excellent sources of pollen and nectar in early spring (Steinkraus, 2010). Recent research has further demonstrated that early-spring flowering bulbs can add color to dormant warm-season turfgrasses and will also provide nutrition to pollinating insects (Wisdom, 2017).

Bulb planting methods

When planting bulbs, it is best to avoid small numbers of bulbs planted in a row, as mass plantings are considered more visually appealing (Dana et al., 2001; Curtis et al., 2009). Historically, traditional planting methods for bulbs required excavating a hole, inserting a bulb into the hole, and covering the bulb with loose soil. Although this is an appropriate method for a small quantity of bulbs, when incorporating large numbers of bulbs into lawns or other expanses, in drifts or informal masses, this approach is both time consuming and labor intensive. Cutting turf as sod and rolling it back like a carpet, then laying bulbs in a random pattern on bare soil beneath has been suggested as an option for large plantings in grassy areas (Bryan, 2002; Hessayon, 1996). However, there have been no studies which have investigated methods of planting in dense, warm-season lawns. If the benefits of early-spring bulbs in lawns are going to be accepted and implemented by the public, efficient planting methods need to be developed. The objective of this study was to examine several planting methods for establishing early-spring bulbs in lawns.

Materials and Methods

A field study was established on 11 Dec. 2015 at the University of Arkansas Agricultural Research and Extension Center located in Fayetteville, AR (36:05:46.8 N, 94:10:28.5 W NAD83, 394 m NAVD88) (Figure 1). A replicate study was established on 14 Dec. 2017 at an adjoining site (Figure 2). The soil at the site was a Captina silt loam (fine-silty, siliceous, active, mesic Typic Fragiudults) with an average pH of 6.2. The area selected for the study was a full-sun site established in 2005 to ‘Riviera’ bermudagrass. Mowing height of the bermudagrass was 7.5 cm and the turf received 7.5 g N/ m^2 of Thrive Branded 46-00-00 Urea Nitrogen (Mears

Fertilizer, Inc. El Dorado, KS), applied in July of each year. In the extended absence of rainfall, supplemental irrigation was applied weekly to a depth of approximately 2.5 cm.

Bulb species, their respective cultivar (if known), and common name are described in Table 1. All bulb species tested in this trial were obtained from a single distributor (Van Engelen Inc., Bantam CT) and selected for their observed performance in gardens in the region and recommendations from local horticulturists (Richardson et al., 2015). Three distinct planting methods were tested in the study. In the first, referred to as "traditional planting" method, holes were drilled to twice the depth of the diameter of the bulb (with turfgrass undisturbed), bulbs were laid directly into the drilled hole, and bulbs were covered with loose soil (Figure 3). In the second, referred to as the "existing sod" method, sod was cut and peeled away, and bulbs were laid directly onto bare soil, with the sod returned to the top of the bulbs (Figure 4). In the third, referred to as "new sod" installation, sod was cut away and soil under the sod tilled to a depth of 7.5 cm to simulate a site that was to be planted in new sod. Bulbs were placed on tilled soil and the sod returned to the top of the planted bulbs (Figure 5). In the last two methods, the sod was cut to a 5.0 cm depth with a commercial sod cutter (Ryan Jr., Schiller Grounds Care, Inc., Johnson Creek, WI). These methods sought to simulate planting techniques that might work for a homeowner with a small amount of bulbs to incorporate into existing sod (traditional method) or a home or business owners seeking to plant larger quantities of bulbs across larger spaces (existing lawn and new sod installation). Bulbs were planted in a 0.9 x 0.9 m area at the center of the plot, with buffers between plots. Bulbs were established in a randomized split-plot design within each planting area, with three replications per bulb treatment and 25 bulbs per replicate. A template was constructed for plot size and was used to mark each planting site, by spraying paint through pre-cut holes. The project control was *Crocus tommasinianus* 'Ruby Giant', a previously tested spring blooming bulb that demonstrated persistence in zoysiagrass at this location (Richardson et al., 2015).

Data collection was primarily focused on establishment, performance, and persistence of bulbs over a two year period (2016-2017). Data collection consisted of weekly counts of plant emergence and flower emergence. Data were analyzed by analysis of variance, with mean separation tests performed by using Fisher's protected least significant difference (p=0.05).

Results and Discussion

In 2016, the main effects of planting method and entry were significant for both vegetative growth and number of flowers, while in 2017, only bulb entry affected the number of flowers produced (Table 2). Although planting method had a significant effect on vegetative and flowering characteristics in 2016, planting method did not affect the second year (2017) performance (Table 2).

In 2016, the traditional planting method resulted in greater vegetative growth than either the existing sod method or the new sod method (Table 3). In 2017, traditional planting method vegetative growth fell to 81.8%, but there was no significant difference between planting method on vegetative growth. In 2016, bulbs that were traditionally planted also produced significantly more flowers compared to the existing sod and new sod planting methods (Table 3). Similar to vegetative characteristics, there was no significant difference between planting methods on flowering performance of the bulbs in the second year of the trial (Table 3).

In both 2016 and 2017, *Muscari* exhibited greater vegetative growth than *Narcissus* but was not significantly different to *Crocus* (Table 4). In both 2016 and 2017, *Muscari* had significantly greater flowering than *Narcissus* and *Crocus* (Table 4). Although *Narcissus* had greater flowering than *Crocus* in 2016, there were no statistical differences between these species in the second year (2017) of the trial.

As noted earlier, a previous study established the viability of *Crocus tommasinianus* 'Ruby Giant' in zoysiagrass (Richardson et al., 2015). However, the planting method used in that study was a hollow-tine cultivator (Toro Co., Bloomington, MN) equipped with 1.6 cm-diameter tines that penetrated the soil to a depth of 10 cm. Soil cores were removed from the site and bulbs were placed in open holes left by the cultivator, then top-dressed with a sandy soil to a depth of 0.6 cm. This planting method was suitable for research purposes but use of the aerator prevented recommendations for mass planting of bulbs; placing assorted bulbs into each void, and then top-dressing individual spaces would be both time and labor intensive. Additionally, most home owners do not have access to a hollow-tine cultivator with 1.6 cm-diameter tines, or top-dressing equipment to restore displaced soil, which would prevent ease of incorporation into a home lawn area. However, landscape professionals and golf course superintendents, who have access to both equipment and labor, might prefer these methods of incorporation.

Bulbs used in this study were chosen for a variety of factors, the most important being observed performance in the region. Based upon the results of the earlier study, that some bulbs have the ability to persist in warm-season turfgrasses, a critical component of this study was to incorporate bulbs that had historically shown persistence in northwest Arkansas. Varieties of *Crocus*, *Muscari*, and *Narcissus* demonstrate the tendency to naturalize in meadows and grassy areas (Bryan, 2002; Leeds, 2000), although this theory has not been tested in warm-season turfgrasses.

Conclusions

Results of this research established that the traditional method was best for first season emergence and flowering. However, data from the second season indicated that bulb persistence, emergence and flowering were not affected by any of the three planting methods. While this information can benefit companies which supply and install warm-season turfgrass sod, it might also be of interest to home and business owners who want to add color and/or pollinator friendly flowering bulbs to their landscapes.

Table 1. Bulb species, common name, and cultivar (if known), of entries used in trial to test various planting methods.

Species	Common name	Cultivar
Narcissus	daffodil	‘Rijnveld’s Early Sensation’
Muscari armeniacum	grape hyacinth	
Crocus tommasinianus	crocus	‘Ruby Giant’

Table 2. Analysis of variance, testing the effects planting method, and bulb entry on vegetative and flowering characteristics of spring bulbs in a bermudagrass lawn.

		2016		2017	
Source	DF	Vegetative	Flowers	Vegetative	Flowers
		------------------------- Pr > F		----------------------------	
Block	2	0.1746	0.6495	0.5234	0.501
Method	2	0.0031	0.0011	0.2132	0.496
Block * Method	4	0.1607	0.7764	0.5867	0.7995
Entry	2	0.0133	<.0001	0.0600	<.0001
Method * Entry	4	0.2189	0.1098	0.8685	0.6147

Table 3. Effect of planting methods on percentage of bulbs planted that produced either vegetative growth or flowers.

	Vegetative			Flowers		
Planting method	2016		2017	2016		2017
	---- % of bulbs planted ----			---- % of bulbs planted ---		
Drill-planted	99.6	A[z]	81.8	84.9	A	61.3
Sod	89.8	B	91.6	57.8	B	61.3
Sod + till	92.9	B	93.3	61.3	B	67.6
LSD (0.05)[y]	4.9		ns[x]	12.8		ns[x]

[z] Within each column, means sharing a letter are not statistically different according to Fisher's protected LSD test ($\alpha = 0.05$)
[y] LSD = least significant difference values ($\alpha = 0.05$) for comparing means within a column
[x] ns = not significant

Figure 1. Photo of experimental area during the first spring after establishment (photo taken 3 Mar. 2016). Sod cuts are clearly visible with (bottom row, from left) sod removal, traditional method, and sod & till method represented. By 2017, bermudagrass had filled in cut areas and demonstrated a uniform appearance (photo by author).


Figure 2. Photo of experimental area taken during incorporation of replicate planting methods study (photo taken 14 Dec. 2017). Sod cuts are clearly observed, with (from left) sod removal, traditional method (drilled spaces marked by blue paint), and sod & till method pictured. Sod was returned to the top of the bulbs after bulb placement onto soil surface. Loose soil was returned to the top of bulbs placed in drilled holes (photo by author).

Figure 3. Traditional Planting Method. Photo of auger attached to a hand-held drill, used to incorporate bulbs into bermudagrass (photo taken 14 Dec. 2017). Bulb placement was facilitated by the use of a pre-cut template, which marked exact planting locations. Loose soil was lightly packed on top of bulbs after bulb placement into drilled holes (photo by author).

Figure 4. Existing Sod Planting Method. Photo of *Narcissus* ‘Rijnveld’s Early Sensation’ bulb arrangement on untilled soil (photo taken 14 Dec. 2017). A pre-cut template was used to mark exact planting locations. Bulbs were laid on their side; sod was returned to the top of the bulbs. After the return of sod to soil, measures were taken not to crush bulbs underneath, by avoiding trafficking areas directly above bulb placement (photo by author).

Figure 5. New Sod Planting Method. Photo of *Crocus tommasinianus* ‘Ruby Giant’ bulb arrangement on tilled soil (photo taken 14 Dec.2017). Bulb placement was facilitated by the use of a pre-cut template, which marked exact planting locations. Sod was returned to the top of the bulbs after bulb placement onto soil. After return of sod to soil, measures were taken not to crush the bulbs underneath, by avoiding trafficking areas directly above bulb placement (photo by author).

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Summary and Conclusions

While turfgrass is often considered a monoculture, managed turfgrass systems can present opportunities for pollinator habitat development. Roadsides, public and private parks, out-of-play areas on golf courses, and home lawns all contain turfgrass areas which might support pollinator friendly plants such as early-spring flowering bulbs and herbaceous flowering perennials, to create a season long succession of resources for pollinating insects.

Early-spring flowering bulbs were investigated for persistence in warm-season turfgrasses and their ability to attract and feed pollinating insects. Thirty early-spring flowering bulbs were tested over a 2-year period in a bermudagrass and buffalograss lawn setting in Northwest Arkansas. This study demonstrated that several bulb entries, including species of *Crocus* spp., *Muscari* spp. and *Narcissus* spp., persisted well in warm-season turfgrasses. The *Crocus* spp. and *Muscari* spp. were also attractive to pollinating insects, while the *Narcissus* spp. were not visited by pollinating insects. In these studies, bulbs were not observed to interfere with the warm-season turfgrass systems in any way.

By incorporating early-spring flowering bulbs into lawns or other turfgrass areas, home and business owners can add color, biodiversity, and nutrition for foraging pollinators, but correct species selection is critical for long-term success.

Although the comprehensive bulb study demonstrated that flowering bulbs can persist in warm-season turfgrasses, establishment of bulbs in lawns could be difficult due to the dense canopy that is present. In a separate trial, three distinct planting methods for bulbs were investigated in a bermudagrass lawn: 1) establishment of bulbs using a traditional auger method 2) removal of sod and laying the bulbs on the soil and returning the sod and 3) removal of the sod, tilling the soil underneath, planting the bulbs, and returning the sod (to simulate a new sod establishment site). Although there was a slight advantage of the auger method during the first spring after establishment, planting method did not affect bulb persistence and flowering after the second season, suggesting that bulbs can be established successfully in warm-season lawns by a variety of methods.

Flowering perennial plants (forbs) were also investigated for persistence and flowering times in bermudagrass, and for their ability to attract and feed pollinating insects. Numerous forbs are commonly found in lawns or other grassy areas that are considered forage sources for pollinating insects. However, some are considered weedy species and have been eradicated from many home landscapes.

Eight entries of perennial forbs were tested in a bermudagrass lawn and were evaluated for persistence over time and their ability to attract pollinators. Two cultivars of white clover were observed to achieve a competitive balance with bermudagrass by the end of the 2-year study period. Another entry, self-heal (*Prunella vulgaris*) also thrived in bermdagrass but was considered to be too invasive in this environment. Finally, spring beauty (*Claytonia virginica*) was also able to persist in a bermudagrass lawn over the 2-year study period. Three species including English daisy (*Bellis perennis*), birds-foot trefoil (*Lotus corniculatus*), and subterranean clover (*Trifolium subterraneum*) did not establish well, produced minimal flowers, and failed to persist in bermudagrass. Pollinator activity was observed on all four of the entries which persisted in bermdagrass, including both white clover entries, the self-heal, and the spring beauty. These results confirm that certain perennial forbs can be incorporated into a warm-season turfgrass such as bermudagrass, both enhancing the biodiversity of the lawn and providing excellent pollinator habitat from late spring to early fall.

Collectively, these studies clearly demonstrate that certain species of early-spring bulbs and perennial forbs can be established into warm-season lawns and provide habitat for pollinating insects. These results can be beneficial to any homeowner or turfgrass manager that seeks to enhance the biodiversity of their turf and create favorable environments to support pollinators.

Appendix
All photos by author

A1.1. 19 November 2015. Incorporating early-spring flowering bulbs into a raised bed. The raised bed was used to test viability of bulbs in Northwest Arkansas.

A1.2. 20 November 2015. Incorporating bulbs into buffalograss.

A1.3. 20 November 2015. Bulbs were covered with composted material.

A1.4. 21 February 2016. Early-spring flowering bulbs in bermudagrass.

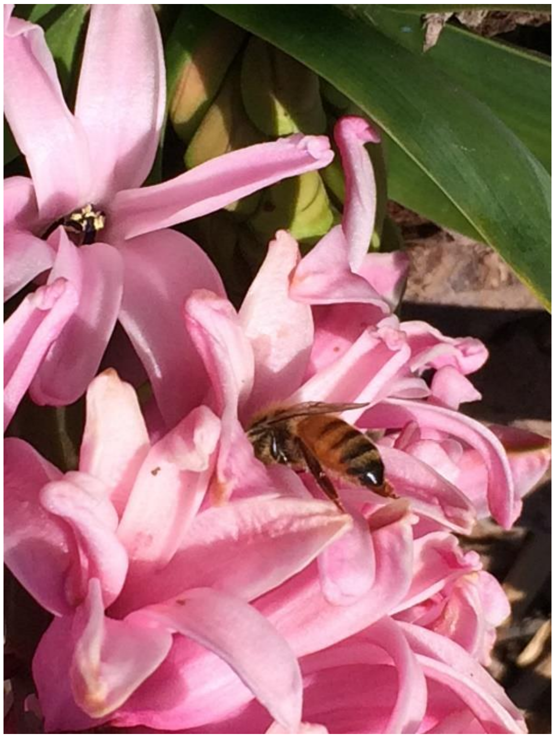
A1.5. 28 February 2016. Early-spring flowering bulbs in bermudagrass.

A1.6. 3 March 2016. Early-spring flowering bulbs in bermudagrass.

A1.7. 10 March 2016. Early-spring flowering bulbs in bermudagrass.

A1.8. 10 March 2016. *Narcissis* ‘Tete-a-Tete’ in buffalograss.

A1.9. 10 March 2016. *Crocus flavus* ‘Golden Yellow’ in bermudagrass.



A1.10. 10 March 2016. Honey bee foraging on hyacinth.

A1.11. 10 March 2016. Hyacinth in bermudagrass. Although hyacinth performed well in the first year of the study, and supplied forage to pollinators, it did not demonstrate persistence in warm-season turfgrasses or the raised bed.

A1.12. 16 March 2016. Honey bee on *Crocus vernus* ‘Remembrance’ in buffalograss.

A1.13. 16 March 2016. Honey bee on *Muscari* in the raised bed.

A1.14. 28 April 2016. Early-spring flowering bulbs in buffalograss, two weeks prior to first mow. Bulb foliage is senescing, sending nutrients into the underground storage structure.

A1.15. 7 February 2017. Early-spring flowering bulbs in buffalograss.

A1.16. 18 January 2017. *Crocus chrysanthus* ‘Cream Beauty’ in buffalograss.

A1.17. 18 January 2017. *Crocus olivieri balansae* ‘Zwanenburg’ in buffalograss.

A1.18. 26 January 2017. Honey bee foraging on *Crocus flavus* ‘Golden Yellow’.

A1.19. 26 January 2017. Honey bee foraging on *Crocus flavus* ‘Golden Yellow’.

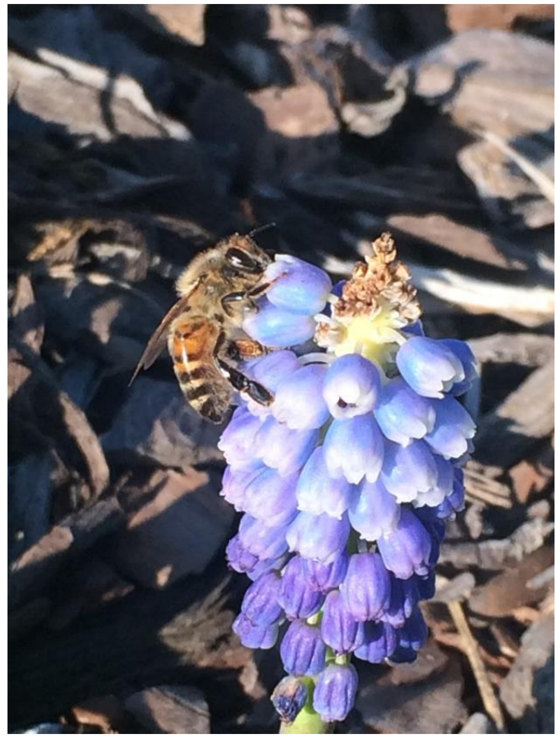
A1.20. 7 February 2017. *Eranthis hyemalis* in buffalograss.

A1.21. 16 February 2017. *Crocus flavus* 'Golden Yellow' in the raised bed. This entry persisted in warm-season turfgrasses while providing forage to pollinators.

A1.22. 18 February 2017. *Iris histrioides* 'Katherine Hodgkin' in buffalograss.

A1.23. 18 February 2017. *Crocus chrystanthus* 'Cream Beauty' in buffalograss.

A1.24. 18 February 2017. Overview of the raised bed.



A1.25. 10 March 2017. Honey bee on *Muscari* in the raised bed.

A1.26. 16 March 2017. Honey bee on *Ipeion uniflorum* in the raised bed.

A1.27. 18 March 2017. Bumble bee on *Muscari* in the raised bed.

A1.28. 16 February 2018. *Crocus isauvicus* ‘Spring Beauty’ in buffalograss.

A1.29. 6 March 2018. *Crocus tommasinianus* ‘Ruby Giant’ in the raised bed.

A1.30. 6 March 2018. *Crocus flavus* ‘Golden Yellow’ in the raised bed.

A1.31. 6 March 2018. *Narcissus* in bermudagrass.

A2.1. 14 March 2016. Flowering perennial plugs in Rosen Alternative Pest Center.

A2.2. 14 April 2016. Incorporating plugs into Riviera bermudagrass.

A2.3. 15 April 2016. White clover in Riviera bermudagrass.

A2.4. 11 May 2016. English daisy in Riviera bermudagrass. English daisy did not persist in bermudagrass beyond the first season.


A2.5. 5 July 2016. White clover.


A2.6. 5 July 2016. Bumble bee on white clover.


A2.7. 17 August 2016. Self-heal (foreground) and birds-foot trefoil.


A2.8. 17 August 2016. Bumble bee on self-heal.

A2.9. 21 February 2017. Spring beauty in bermudagrass.

A2.10. 21 February 2017. Spring beauty, a corm, persisted in bermudagrass in Northwest Arkansas over at least three growing seasons. Photo illustrates flowers and foliage within bermudagrass.

A2.11. 11 April 2017. White clover demonstrating early season competition with bermudagrass.

A2.12. 19 July 2017. Self-heal suppressed bermudagrass over two growing seasons.

A3.1. 14 December 2017. A template was used to mark planting sites.

A3.2. 14 December 2017. Soil was tilled to simulate a new lawn construction.

A3.3. 23 March 2016. *Crocus tommasinianus* 'Ruby Giant' illustrating Traditional Planting Method.

A3.4. 23 March 2016. *Muscari armeniacum* illustrating Cut Sod Planting Method.

A4.1. 28 March 2016. Honey bee on dandelion (*Taraxacum* spp.). The author observed honey bees foraging on dandelions throughout the study period. Dandelions are an excellent early-season source of nutrition for pollinating insects (Steinkraus, 2010).