UTILIZING COOL-SEASON GRASSES IN A NATIVE MID-ATLANTIC FLOWER VISITOR SUPPORTING MEADOW MIX AND TESTING ITS SUITABILITY FOR SOD PRODUCTION

by

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ABSTRACT

Due to human development, grasslands and meadows are the most endangered ecosystems in the United States. Within the Mid-Atlantic meadows are transitional ecosystems, requiring yearly management practices such as mowing or controlled burns. Meadows are essential for endangered pollinator species, support numerous trophic levels, and provide regulating ecosystem services with less inputs than other managed landscapes. Mimicking the prairies of the Midwest, designed meadows often contain native warm-season grass and forb species; however, regional meadow remnants have been shown to have greater richness of native cool-season grasses than warm-season. This research attempts to 1) identify the appropriate establishment time and rates for a cool-season grass dominant meadow; 2) determine whether cool-season grass meadows will support flower visitor communities; and 3) determine the suitability of a native cool-season grass dominant meadow mix for sod production.

Native fescue and bentgrass-based meadow seed mixes, sown at 0.5x, 1x, and 2x densities, in spring and fall were used to evaluate establishment success via germination rates, vegetation composition, weed pressure, species richness and diversity. The fescue mix resulted in higher rates of germination, as did the 0.5x seeding rate. The most significant effect on germination and coverage was the season of sowing. Spring sowing resulted in greater forb coverage while cool-season grasses predominated the fall seedings. Spring sowing had less unoccupied plot space with fewer weeds and resulted in greater species richness.

In year two, we monitored flower visitation (May to Sept) in spring sown plots to the insect morphospecies level. Plant species were the primary drivers of visitation. Anise hyssop accounted for most of these visits (55%). Some visitor interactions were

highly specific, as documented between partridge pea and bumblebees. Bumblebees accounted for 97% of all visits received by this species. Our data indicates that insect morphospecies diversity is supported by plant species diversity.

Simplified versions of the fescue and bentgrass mixes at the 0.5x, 1x, and 2x rate were then tested for their ability to create and establish forb-rich meadows via sod production in a greenhouse. The mixes were later revised for a field application grown in three cm of an engineered sandy loam spread evenly over four mil plastic. The greenhouse wildflower sod transplanted successfully, but early forb species predominated soon after, leading to a significant reduction in species richness. The mixes were revised to be less species rich and utilize a fescue or a bluegrass base for the field application at 0.5x, 1x, and 2x rates. These mixes resulted in fairly low species richness, but did not lose richness as a result of transplant. While still a new area of investigation, meadow sod production shows enough promise to warrant further research.

Certain native cool-season grasses are a viable alternative to warm-season grasses as a base when establishing meadows and flower visitor habitat in the Mid-Atlantic. Our data supports that the diversity of flower-visiting morphospecies is supported by the diversity of forbs. A spring sowing is the best method to establish and support forb-rich meadows that attract a diverse group of flower-visiting morphospecies in the Mid-Atlantic.

INTRODUCTION

As part of the University of Delaware Botanic Garden (UDBG) master plan, a native meadow is proposed to be incorporated into an open space outside of Townsend Hall. Much of the data regarding the establishment of meadows is anecdotal. Quantifiable data that does exist has often been collected from prairie restorations in the Midwest and its applicability to other regions may vary. With landscape professionals and clients having an increasing interest in native plants and imitating natural ecosystems (Butler et al., 2012; American Society of Landscape Architects, 2017), this situation is a great opportunity to establish research to examine new methods of meadow establishment and provide quantifiable data to inform the success of meadow establishment in the Mid-Atlantic.

Most natural meadows in the Mid-Atlantic are warm-season grass dominant (Dickerson et al., 1997; Latham, 2008), so any examination of suggested species for meadow and prairie plantings shows a strong preference toward warm-season grasses (Zimmerman, 2010). Warm-season grasses, however, are prone to limit visibility due to their height and if not controlled properly can dominate meadows (Howe, 1995; Zimmerman, 2010), limiting desired ecosystem services such as attracting pollinators and allowing human use. Utilizing cool-season grasses in meadows could have wider applications in wildflower sod production. Native warm-season grasses are often not ideal candidates for sod production, due to their deeper root systems (Brown et al., 2010). These deeper roots can cause issues for the structural stability of the sod and can cause these species to suffer once transplanted. Additionally, once transplanted, many of these species can get very tall and outcompete native wildflowers over time.

There are three main objectives to this research. These objectives are to: 1) identify the appropriate establishment time and rates for a cool-season grass dominant meadow; 2) determine whether cool-season grass meadows will support flower visitor communities; and 3) determine the suitability of a native cool-season grass dominant meadow mix for sod production. To achieve these objectives, data were collected from cool-season grass meadow plots using author-designed seed mixes. Data collected on the germination rates of spring vs. fall sown plots, persistence of plant species diversity, plant community composition, flower visitation rates, and diversity of flower visitors at the morphospecies level were used to evaluate these research objectives. Differences in weed pressure and richness and colonization of native species between spring and fall sowings were also examined. Insect flower visitation was compared between the spring sown cool-season grass meadows. A meadow sod was also developed in an attempt to circumvent the weed pressure that comes with the seeding of meadows, as well as enable a simpler and less labor-intensive method of establishment when compared to the process of direct seeding.

Given the lack of research and market availability of cool-season native grass dominant seed mixes for meadows, we hope to lay the groundwork for their inclusion in various development projects and in ecologically focused horticultural designs. Meadows are typically transitional ecosystems within the Mid-Atlantic since climax vegetation in the region is deciduous woodland (Latham and Thorne, 2007). Regular, but infrequent, human intervention is required to sustain a designed meadow, thereby giving these ecosystems a degree of novelty. Despite this novelty, meadows are nothing new to the Mid-Atlantic, having been maintained by Native Americans with fire when environmental conditions would not support meadow habitats (Pauly, 1997).

By creating a cool-season grass dominant meadow, we are essentially creating a doubly novel ecosystem that could serve significant niche purposes, for sites that have been considerably disturbed, or to provide coverage at times when warm-season grass meadows typically do not.

Cool-Season Grasses

Cool-season shortgrasses are frequently used as turfgrasses throughout the Mid-Atlantic region. Most are introduced species, but native cool season grasses can also serve this purpose (Zimmerman, 2010). Turfgrass is a predominant feature of urban and suburban landscapes, which occupy much of the Mid-Atlantic and offers a less robust suite of ecological services (Milesi et. al., 2005). In converting urban lawn space into meadows, invertebrate species richness was found to increase with both vegetation height and meadow species richness (Norton et al., 2019). Soil microbial richness and fungal richness were also found to be influenced by plant species richness in 0-10 cm of soil, and vegetation height at 10-20 cm soil depth (Norton et al., 2019).

Turf, when managed properly, can prevent nutrient runoff and provide soil infiltration at levels similar to meadows (Bachman et al., 2016). Properly maintaining turf, however, requires more intervention than the occasional management practices that meadows require (Zimmerman, 2010). Turfgrass production and management is also a major economic industry serving recreational and professional sports fields, lawns, and public spaces throughout the United States (Haydu et al., 2002). Cool-season grass meadows could offer new avenues of high-value crops for these growers, such as meadow sod.

Requiring regular mowing, lawns can be labor intensive to maintain over time when compared to meadows (Zimmerman, 2010). If homeowners were to devote a portion of their yard to a yearly mowed meadow mix, they would reduce the labor and natural resources needed to maintain their lawns, while simultaneously providing greater ecological value to the suburban landscapes by increasing pollinator food sources. Golf courses could benefit from a similar approach. While a portion of a golf course must be maintained for play, there are large areas outside the bounds of play that are often maintained as turf. Replacing some of these areas with a native shortgrass meadow would provide ecological benefits such as pollinator forage sources, habitat for insects and birds, and help provide ecosystem regulating services without the necessity of frequent management practices. These areas can be aesthetically pleasing and would not obscure the view of areas maintained for play. Additionally, cool-season grass meadow seed mixes could serve a use in roadside and brownfield restorations. There is increased interest in not just what our landscaping choices can do for us, but what regulating and provisioning services they can provide for wildlife (Duke et al., 2016). Turf serves a purpose, but meadows contribute more than conventional lawns and the disappearance of native grassland has had reverberations throughout numerous trophic levels (Latham and Thorne, 2007; Tallamy, 2007). Reverberations can be seen through multiple trophic levels because insects are often utilizing this space as a habitat while also being a food source for other larger organisms (Tallamy, 2007).

Providing a meadow seed mix that uses cool-season grasses as its base would assist in creating an aesthetically pleasing and ecologically functional landscape. These cool-season grass landscapes would be able to remain visually cohesive with surrounding turfgrass areas, as many cool-season grasses stay green through the winter while warm-season grass areas among turf areas would be noticeably brown. Although forbs would be brown through the winter, they would have likely senesced to a point where enough light can pass through to the cool-season grasses to allow some off-season photosynthesis and slow growth. Given the dense growth habits and size of native warm-season grasses, their uses can be limited in areas where a desire for ecological functionality intersects with the visibility and space requirements necessitated for roadside and recreational use.

We anticipate forbs will face less competition in cool-season grass meadows than in those comprised largely of warm-season grasses. Cool-season grasses have been shown to have shallower root systems than native warm season-grasses (Brown et al., 2010). As the cool-season grasses begin to slow their growth in early summer, the forbs are entering their primary growth period and will help shield the temperature sensitive cool-season grasses from the sun. Therefore, the generally more expensive forb seed could be sown at a lower rate due to reduced summer grass competition. Also, due to the differences in root depth, forbs may not face as much competition when mixed with cool-season grasses.

Cool-season shortgrasses are well-suited for sod production. A meadow sod could be used to establish meadows where horticultural expertise and time are in short supply, such as with many homeowners and roadside vegetation projects. Sod is a quick and reasonably easy way to establish a lawn. A mix of cool-season shortgrasses and native wildflowers that will be able to hold together when cut and rolled could provide a near immediate meadow for many consumers. A meadow sod would also reduce the germination of weed seed compared to a seeded meadow on a newly tilled site.

Chapter 1

BEST MANAGEMENT PRACTICES FOR MEADOWS WITHIN THE MID-ATLANTIC

There is little data on the best methods for establishment and successful maintenance of meadows in the Mid-Atlantic. The limited data is primarily from landscape firms that specialize in meadows, as well as organizations who promote conservation and better ecological practices, such as The Xerxes Society. In many cases, those writing about meadow establishment and maintenance in the Mid-Atlantic are utilizing sources describing land management practices for Midwestern prairies. In what follows, I treat Mid-Atlantic specific sources and those on Midwestern prairies equally.

Rising Interest and Challenges for Meadow Establishment in the Mid-Atlantic

Increased interest in native plants and pollinators (Butler et al., 2012; American Society of Landscape Architects, 2017), has brought on a popularity surge in constructed GMS systems. In the last few years several books have been published by prominent horticulturists outlining different methods for constructing GMS ecosystems (Rainer and West, 2015; Weaner and Christopher, 2016; Hitchmough, 2017). At the same time there is little quantifiable data to back up many of the recommendations for establishing GMS ecosystems, especially within areas where GMS ecosystems are somewhat novel, such as the Mid-Atlantic.

GMS ecosystems are threatened worldwide but are particularly beleaguered in the Mid-Atlantic due to deciduous forests occupying the role of climax vegetation (Latham and Thorne, 2007). Anthropogenic forces have degraded or destroyed GMS ecosystems further with urbanization being a leading natural cause for species endangerment (Czech et al., 2000) and agricultural development having been the greatest threat to GMS ecosystems in the 20th century in Pennsylvania (Latham and Thorne, 2007). The same is likely true of other Mid-Atlantic States, but significant surveys of their GMS remnant habitats have not been done.

Public support of constructed naturalistic landscapes utilizing native plants is generally poor until the benefits of such a landscape are explained (Rodriguez et al., 2016). These landscapes, despite their benefits, are still consistently less diverse than natural GMS habitats due to a lack of availability of many GMS plants in the horticultural trade. Warm-season grasses tend to dominate the planting choices of these designed ecosystems (Latham, 2008), partly due to their C4 photosynthetic pathways, giving them a competitive edge during the warmer seasons. Management practices such as early spring mowing and burns that enable meadows to persist are often unintentionally carried out during times that favor warm-season grasses, due to the safety hazards they can pose for humans, leading many designed or restored meadows to eventually become warm-season grass dominant (Howe, 1995; Zimmerman, 2010). There is, however, greater species richness of cool-season grasses than warm-season grasses within Mid-Atlantic GMS habitats (Latham and Thorne, 2007).

While there have not been widespread surveys of the establishment of designed GMS habitats within the Mid-Atlantic supported with quantitative evidence, there are many examples of successfully established constructed warm-season grass dominant GMS. Cool-season grasses, within a meadow setting, are nearly entirely absent from existing literature surrounding GMS habitats.

The State of Grassland, Meadow, and Savanna Ecosystems in the Mid-Atlantic

While there is very little research on the role of meadow ecosystems in the Mid-Atlantic, Latham and Thorne compiled a large review of state-owned land within Pennsylvania in an effort to identify potential grassland/meadow reclamation sites, identify historic remnants of grassland/meadow ecosystems, and assess the state of plant and wildlife species that depend upon these ecosystems (Latham and Thorne, 2007). While meadow is often used as a horticultural catchall for naturalistic plantings featuring grasses and forbs, largely absent of woody material, Latham and Thorne put forth a more accurate description of grassland ecosystems in the wild. What distinguishes the grassland, meadow and savanna (GMS) ecosystems are the types and degree of vegetation coverage: grasslands have over 50% grass cover with few or no trees, meadows over 50% forb cover with few or no trees, and savannas are dominated by grasses or forbs with scattered shrubs and 5-25% canopy cover (Latham and Thorne, 2007). Prairies and meadows differ from one another as well, with prairies being primarily maintained by fire and meadows being maintained through other natural processes, such as drought, flooding, human intervention, (Delaney et al., 2000) or geologic formations (Rajakaruna et al., 2009). Soil pH is sometimes considered the distinguishing characteristic between meadows and prairies, with meadows having more acidic soils, while prairies are more alkaline (Weaner and Christopher, 2016). Prairies can be divided further into tall-grass, short-grass, and mixed grass, wherein annual rainfall is generally the determining factor on the grass type of the prairie (Gardner, 2011).

Worldwide, temperate GMS landscapes are largely unprotected, with only 4.6% receiving protection and 45.8% having already been destroyed (Latham and Thorne, 2007). Given that GMS ecosystems are typically transitional in the Mid-

Atlantic due to rainfall levels and a prolonged lack of disturbance (Latham and Thorne, 2007), these ecosystems are particularly beleaguered. Within the Mid-Atlantic, some of the most notable GMS ecosystems are maintained in a state of arrested development through serpentine rock formations that inhibit the growth of woody climax vegetation (Rajakaruna et al., 2009). Several species of plants are only found in these serpentine outcrops (Rajakaruna et al., 2009). In Pennsylvania, as of 2007, of the vascular plant species that could reasonably be considered to grow in GMS ecosystems, 38% are state-endangered species, 41% are state-threatened species, and 35% have been extirpated (Latham and Thorne, 2007).

Insects rely on these ecosystems. Of Lepidoptera species classified as endangered, threatened or rare in Pennsylvania, 74% of butterfly and 38% of the moth species rely on GMS habitats either wholly or in part due to specialist larval feeding requirements on hosts native to these ecosystems (Latham and Thorne, 2007). The pressures affecting native grassland species have reverberating effects through other trophic levels (Tallamy, 2007). The native plants found in GMS ecosystems, serve not only as habitat, but as food sources for insects; these insects are then food sources for other organisms, most notably birds (Tallamy, 2007). Birds, too, are directly impacted by the loss of GMS habitat, as 15 species within Pennsylvania are grassland-obligate or grassland-interior species (Latham and Thorne, 2007). The contiguous habitat required for these species is a minimum of 40 to 101 hectares, but small populations of individuals can be supported by 5 to 10 hectares (Latham and Thorne, 2007). The islands of suitable habitat across the United States are, today, “far too small to sustain populations of living things for very long” (Tallamy, 2007). If successful, cool-season grass dominant meadows or meadow sod use around residential landscapes and spaces of recreation could help to mitigate these problems, but still leave habitat areas fragmented. More research is required to determine whether an abundance of smaller fragmented grasslands could support some of the grassland obligate birds and insects.

Plant Selection and Seed Selection

A meadow planting aims to replicate or mimic natural ecosystems by recreating the communities of plants therein (Zimmerman, 2010). Rainer and West recommend combining species with related cultural requirements, utilizing the abiotic and biotic stresses of a site as an asset in selecting plant species adapted for the area and densely planting in multiple vertical layers to hinder weed pressure (Rainer and West, 2015). Weaner and Christopher echo these recommendations and note that one of the first considerations should be the aggressiveness of the plant species (Weaner and Christopher, 2016). Diboll, in *The Tallgrass Prairie Restoration Handbook*, recommends designing a seed mix around the following concerns: site conditions, restoration goals, grass-to-forb ratio, seed quality, seeding rates and seed size, germination rates and reliability of each species, ecological behavior, efficiency of seeding techniques, planting season, and budget (Diboll, 1997).

Many meadow planting recommendations tend to favor native plant selection; however, this is not a necessity of establishing a meadow from seed. Hitchmough has strayed from the native heavy approach, instead seeking to have community design “meet human aesthetic needs and environmental conditions” by mixing geographically diverse, but culturally similar plants from locations such as the American prairies and the Asian steppes (Hitchmough, 2017). Given the ecological approach to many of these projects, seed from local ecotypes is often preferred; this is especially true of restoration projects wherein plants are recommended to be as local as possible

(Delaney et al., 2000). Ranges of what is considered local can vary between a few kilometers to up to 300 kilometers from the project site (Delaney et al., 2000). Some experts recommend collections from areas within 24 kilometers (Gardner, 2011).

The species that often comprise meadow communities are well documented on a superficial level. Numerous sources cite many of the same plants as suitable for meadow plantings/restorations (Shirley, 1994; The Xerces Society for Invertebrate Conservation, 2015; Zimmerman, 2010). In Pennsylvania alone, there have been "60 grasses, 80 other graminoids (sedges and rushes), and nearly 400 forbs" identified as suitable for reclamation use, excluding 237 species of special conservation concern (Latham and Thorne, 2007). Many species, however, remain outside of the horticulture and restoration trade. Latham and Thorne note, "at present, less than one-fifth of the native herbaceous species (but including more than one-quarter of the grasses) most qualified for GMS reclamation planting are commercially available as seeds of native Mid-Atlantic genotypes" (Latham and Thorne, 2007). An example from the research herein was the seed of *Viola sororia* Willd., a common native plant in the Mid-Atlantic, that had limited availability commercially and was very expensive.

Plant communities designed for meadows often utilize warm-season grasses to compliment the forb species represented (Weaner and Christopher, 2016). Warm-season grasses are typically widespread throughout naturally occurring meadows across the Mid-Atlantic (Latham, 2008), but cool-season grasses are also present; within Pennsylvania there are 92 native grass species found in GMS habitats, and of these 92 grasses, 49 are cool-season and 43 are warm-season (Latham and Thorne, 2007). Designed meadows, however, tend to feature fewer cool season grasses.

Weaner and Christopher describe warm season grasses as, “largely compatible with native wild-flowers,” while noting that cool-season grasses, “tend to be mat forming, and those that are commonly encountered in North American landscapes are mostly of European origin” (Weaner and Christopher, 2016). They also remark that, “fields dominated by European cool-season grasses in North America rarely contain significant numbers of American native wildflowers,” but frequently contain European wildflowers such as *Daucus carota* L. (Weaner and Christopher, 2016). The reason attributed for the presence of *D. carota* is that cool-season grasses tend to be shallow rooted, and thus *D. carota* with its taproot is adequately adapted to a cool-season grass landscape (Weaner and Christopher, 2016) by accessing moisture and nutrients below the shallow rooted cool-season grasses. Many meadow forbs are deep rooted as well (USDA-NRCS, 2004), and should be able to compete with cool-season grasses, even if they are somewhat mat forming. The University of Maryland notes both *Festuca trachyphylla* (Hack.) Krajina and *F. ovina* L. (two grasses of European origin) as suitable for meadows (Krouse et al., 2003). While there are many mat forming cool-season grasses utilized for turf, there are also many cool-season bunch grasses. Several warm-season grasses are also suited for sod production due to their mat-forming habit. Additionally, we know there are cool-season grasses present within the meadows of the Mid-Atlantic (Latham and Thorne, 2007), though the significance of these populations does not seem to have been determined. The claim that cool-season grasses are ill-suited for meadow usage is a broad generalization that fails to deal with the morphological diversity of our native grasses.

The first step to designing a meadow seed mix is to determine the ratio of grasses to forbs. Diboll recommends a mix with 50-60% by weight of forbs to grasses, noting that lower rates of forbs tend to quickly yield grass dominated prairies and that too high a rate of forbs tends to burn poorly when prescribed burns are carried out (Diboll, 1997). Shirley recommends 60-75% forb seed for a dense stand, and at least 50% grasses when wildlife cover and food are desired outcomes of the sowing (Shirley, 1994). A mix of at least 40% grasses is recommended by Weaner and Christopher (2016). A study by the Tallgrass Prairie Center examined the rates of establishment of three seed mixes (a 1:1 grass to forb diversity mix, a 1:3 grass to forb pollinator mix, and a cost-effective 3:1 grass to forb mix) and found that the 1:1 mix established well, was still relatively low-cost and sustained pollinator forage plants equivalent to the amount in the 1:3 grass to forb pollinator mix (Meissen et al., 2017). The 3:1 grass to forb mix also established well, but supported very few pollinator forage plants (Meissen et al., 2017). The 1:3 grass to forb ratio had difficulty establishing and was not cost-effective (Meissen et al., 2017).

In developing our own plant list, as well as the representation of species within the total mix, the considerations above were utilized. Additionally, unpublished trial data of grass and forb establishment in Maryland was utilized (Brader, unpublished data). Seeds were generously donated for much of this and associated research; for this reason, preference to seeds of local provenance was waived. Further studies that examine the effectiveness of meadow establishment from seed of local ecotypes versus those of unspecified provenance would be valuable but are outside the scope of this research. For a complete overview of all species included within this seed mix and the attributes that encouraged their inclusion see Appendix A.

Site Preparation

Preparing a site for a meadow installation should seek to match plants to the habitats and microhabitats within the site (Weaner and Christopher, 2016). The reasoning here is twofold: any changes to the existing site, such as changing the soil pH, will require significant inputs and are likely to be temporary over the longer term of management (Rainer and West, 2015). Shirley affirms the importance of knowing the soil pH and encourages the selection of species based on the soil type present (Shirley, 1994). She also states that most wildflowers will do best with a pH of 6.5, but recognizes many have much wider ranges of tolerance (Shirley, 1994). Additionally, changing the site directly impacts a community's ability to adapt. Plant communities are designed by selecting plants that work well together and possess adaptations fit for the challenges that are present at each site (Rainer and West, 2015). The goal of low impact design is to align intervention with natural processes such as soil building, plant competition, and ecological succession (Rainer and West, 2015). In the event of soil compaction, drill-seeding is an effective sowing method to overcome the compaction, without opening the soil up for weed seed germination (Barton et al., 2009).

The first step to establishing a meadow is the removal of existing plant material. Depending on the status of the land to be used, an inventory of existing species worth preserving may be warranted (Delaney, et. al, 2000). A non-selective herbicide is a highly effective method to clear the site of undesirable vegetation (Weaner and Christopher, 2016). Non-selective herbicide applications, along with a no-till approach, was found to be more effective than tillage-only preparation when establishing pollinator habitat (O'Rourke et al., 2017). In smaller sites, mechanical barriers such as a combination of cardboard, newspaper, and weed-free mulch may be effective to remove existing vegetation (Weaner and Christopher, 2016; Zimmerman, 2010). Mechanical barriers will need to be in place for an extended period, from three months to one year, to remove existing vegetation (Zimmerman, 2010), and are typically more expensive and labor intensive to implement (Weaner and Christopher, 2016). When lawn is being converted to meadow space, a sod cutter may be used to remove the first 7.6 cm of grass and soil, as well as much of the weed seed bank (Shirley, 1994). Alternatively, a propane torch could be used to singe the existing vegetation and kill some of the existing root systems (Zimmerman, 2010). Solarization is another method that can be used, wherein the area is covered with black plastic that smothers the existing vegetation and existing weed seeds are destroyed due to heat (Delaney, et. al., 2000). Shirley recommends a more thorough, but labor-intensive approach of tilling one full year prior to planting, sowing a cover crop, and spot-treating with glyphosate to remove emerging weeds (Shirley, 1994). No-till is recognized as being viable but is not recommended for areas with significant weed seed content (Shirley, 1994). Even if the weed seed bank is high, tilling may cause more harm than good by providing advantageous conditions for weed seed, while also contributing to the likelihood of erosion and damage of soil ecosystems and organisms (Kladivko, 2001; Weaner and Christopher, 2016; Melman et al, 2019). These methods should be applied as suited to the site. For this experiment we chose to utilize applications of glyphosate to remove vegetation at the site, as it is the least intensive and quickest way to remove vegetation.

Calculating Seeding Rates

Several methods of calculating seeding rates for meadow planting are in common use. All methods measure seeds in amounts of pure live seed (PLS). PLS is the percentage of seeds that are likely to germinate once the germination rate and purity of the seed have been accounted for (Houck, 2009; Weaner and Christopher, 2016). To calculate the % PLS, the % purity and % germination of the lot are multiplied. The weight of seed is then divided by the % PLS. The weight of PLS accounts for the additional seed needed to counter the lack of purity and unviable seeds in the seedlot.

One method of calculating seeding rates is to focus on a suggested number of seeds per area (typically square feet in the United States and square meters elsewhere) (Tallgrass Prairie Center, 2015a; Weaner and Christopher, 2016; Hitchmough, 2017). Weaner and Christopher utilize an equation to calculate seeding rates with this method. The area of the project site is multiplied by the total number of seeds desired per area of measurement which is multiplied by the percentage of the mix that a species will represent (Weaner and Christopher, 2016). The figure derived from this equation can then be divided by the number of seeds of a species in a set weight to determine the total weight of seed needed. There is, however, discrepancy over what density of seeding is sufficient. The University of Northern Iowa's Tallgrass Prairie Center recommends a density of no fewer than 430 seeds per m^2 and an ideal density of approximately 650 to 850 seeds per m^2 (Tallgrass Prairie Center, 2015a). Diboll also recommends utilizing this method, with a target density of seeds at 430 to 645 seeds per m^2 (Diboll, 2017). He notes that this rate translates to roughly 7.85 kg per hectare (Diboll, 2017). Weaner and Christopher recommend 860 to 1885 seeds per m^2 (Weaner and Christopher, 2016). The method used by Hitchmough is essentially the same, but he also adjusts the equation to include a rate of field emergence (Hitchmough, 2017). Field emergence, however, is not a metric often tested when ascertaining the viability of a seed lot, but the differences between field emergence rates, Hitchmough asserts, is “at most a three-fold difference” (Hitchmough, 2017). Most of the data Hitchmough uses to calculate field emergence rates are from his own trials, so most seed houses would not be able to provide comparable data.

The problem with determining a seeding rate from a predetermined density of seedlings per unit of space is that the number chosen is arbitrary. At best, a number is selected between a suggested range, but this only accounts for the amount of seed present pre-germination and does not clearly provide any information about how the landscape will look after germination. If 25% coverage of *Schizachyrium scoparium* (Michx.) Nash is desired, the amount of seed required is unclear. If 25% of the seeds in one m^2 are *S. scoparium* the result would likely be a field of *S. scoparium* with little diversity. Hitchmough offers some suggestions for how to best account for species composition and desired density by noting, “species that grow very slowly or are small…or are less shade tolerant, highly attractive, or long flowering are put at higher densities, whereas species that are fast growing or large, flower for a shorter time period, or are less attractive are put in at a lower density” (Hitchmough, 2017). None of these qualities have any bearing on how prolific a species may be over time. In a restoration or reclamation project a correlation between ecological value and attractiveness or culture cannot be assumed. Similarly, species may be a mixture of any of these qualities that Hitchmough suggests, making discerning rates difficult and still arbitrary.

Another method of calculating seeding rate is by looking at the suggested rate of seed for establishment of an adequate monostand (Houck, 2009). Seeds per square meter are taken into consideration when determining the weight of seeds required to produce an adequate monostand, but seeds per sq. meter can differ drastically from species to species. Typically, species fall somewhere within the range of 215 to 645 seeds per m^2 to achieve an adequate monostand, but some species may require as few as 20 or as many as 2600 seeds per m^2 (Houck, 2009). Considerations that determine how many seeds should be used are mature plant size, plant type, and planting methods (Houck, 2009). The Natural Resource Conservation Service (NRCS) has data regarding the establishment of species in restoration projects. However, for some species there are no data regarding the amount of seed required to create an adequate stand since these species never create large stands on their own in the wild and have no agricultural value, and therefore are not typically sown as a monoculture.

By utilizing the NRCS's method of determining a seeding rate, a better idea of the meadow's initial composition can be determined. For example, if 25% coverage of *Schizachyrium scoparium* within a meadow is desired, and 11.2 kg of pure live seed (PLS) per hectare is recommended for full coverage, there should be 2.8 kg PLS per hectare of *S. scoparium* in the final seed mix. One can reasonably then assume that under ideal conditions 25% of the meadow will be covered by *S. scoparium*. It is important to note that the variability of site conditions is not considered here. Some species may more successfully establish under certain site conditions, but not in another.

Both methods of calculating seeding rates could be used complementarily. If the NRCS method is used, attention should be paid to how many total seeds are being sown per square meter and the species total representation in the mix be adjusted to accommodate the suggested range of seeds per square meter. To determine a seeding rate, the NRCS data regarding establishment of an adequate monostand should be utilized to determine whether a species will be seeded adequately with the rate of seeds per square meter desired.

In *Restoring the Tallgrass Prairie*, Shirley describes a slightly different process of determining seeding rates. Her method utilizes elements that have been discussed thus far. She begins by determining a forb-to-grass ratio by weight and then selects a target seeding rate that is between 9 to 22.5 kg per hectare (Shirley, 1994). To determine the weight of seeds needed, Shirley utilizes the quantity of seeds per pound to estimate the amount needed by calculating the mean seed size within the mix (Table 1.1) (Shirley, 1994). Mixes that are made up of species with larger seed will then require a greater weight purchased, while mixes containing many smaller seeds will require less weight. The total mixture should be sown at a rate of 320 to 645 seeds per sq. meter (Shirley, 1994).

Table 1 Reproduction of Table 4 from Shirley, 1994, *Restoring the Tallgrass Prairie*. Metric conversions are my own. Seeds per kilogram rounded to the nearest hundred.

Seeds per pound	Pounds per acre	Ounces per 1,000 sq. ft.	Seeds per kilogram	Kilogram per hectare
9,000,000	0.5	0.2	4,082,300	0.56
3,200,000	1.0	0.4	1,451,500	1.12
1,800,000	2.0	0.8	816,500	2.24
850,000	3.0	1.2	385,600	3.36
600,000	4.0	1.6	272,200	4.48
500,000	5.0	2.0	226,800	5.60
473,000	6.0	2.4	214,500	6.73
370,000	7.0	2.8	167,800	7.85
320,000	8.0	3.2	145,100	8.97
250,000	9.0	3.6	113,400	10.09
200,000	10.0	4.0	90,700	11.21
138,000	12.0	4.8	62,600	13.45
122,000	15.0	6.0	55,300	16.81
102,400	20.0	8.0	46,400	22.41
73,000	25.0	10.0	33,100	28.02
7,000	30.0	12.0	3,100	33.63

Other considerations to account for when determining seeding rates are the ecological behavior of each species, time of sowing, the reliability of species germination, and budget restrictions (Diboll, 1997). Utilizing the PLS value of each species allows the weight of seed present in the mixture to be the weight of predicted viable seed; however, some species still may not germinate due to unfavorable conditions despite the site itself being suitable to the species (Diboll, 1997). Additionally, the growth patterns of species need to be taken into consideration, as forb mixes that are too heavy in early successional species will lack longevity or stunt the growth of slower growing species (Diboll, 1997). Mixes too high in slower growing species may take years to establish (Diboll, 1997). The time of sowing may also warrant adjustments to the seeding rates as early spring, late spring, summer and fall sowings can all favor different species (Diboll, 1997).

Sowing

Methods of sowing are generally determined by the topography and size of the site (Barton et al., 2009). Typically, larger sites are more easily seeded through methods such as drill seeding (Barton et al., 2009). Traditional drill seeding requires the area to be relatively flat, the division of seeds by size, and typically requires seeds cleaned of any beards or awns (Tallgrass Prairie Center, 2015b). Most seed drills do not accommodate the fluffier seed of warm-season grasses, and thus brands of seed drills that allow the separation of seed, resulting in more uniform distribution of sowed seed are required (Barton et al., 2009). In areas where slopes are too steep for drill seeding, or are otherwise difficult to access, hydroseeding may be used to ensure coverage of areas up to 61 m away (Barton et al., 2009). Hydroseeding tends to work better with rapidly germinating cool-season grasses than with the slower germinating warm-season grasses; however, applications can be adjusted to compensate for the differences in germination (Barton et al., 2009). When seeding by hand, Diboll recommends increasing the overall seeding rate by 25% (Diboll, 1997).

Smaller sites are typically broadcast seeded, either by hand, with a spreader, or with a rake; in all cases a carrier is needed to ensure an even spread of seed. There are many suitable carriers, but care should be taken to match a carrier to the specifics of the site. For instance, sites high in organic matter likely will not benefit from compost being utilized as a carrier. Ideally, a carrier should ensure an even dispersal of seed, provide a good environment for germination, and assist in reducing the germination of dormant weed seeds by blocking out light. Barton et al. (2009) suggest sawdust, mushroom compost, and composted yard waste as carriers, but warn against carriers containing excessive amounts of nitrogen in order to reduce weed pressure (Barton et al., 2009). Weaner and Christopher advocate for sawdust and wood shavings (Weaner and Christopher, 2016). The Tallgrass Prairie Center recommend floor absorbent, cracked corn, vermiculite, or scoopable cat litter as carriers (Tall Grass Prairie Center, 2015b).

Ideal sowing time is variable and sowing times may favor some species over others. Determining when to sow is based on considering the consequences and benefits of weed pressure, moisture, and stratification (Shirley, 1994). Weaner and Christopher recommend spring through early summer for a live seeding, and autumn for a dormant seeding (Weaner and Christopher, 2016). Site location is important as dormant seeding on slopes may suffer from erosion and seed loss during snowmelt (Tallgrass Prairie Center, 2015b; Weaner and Christopher, 2016). Sites prone to heavy weed infestation can benefit from a summer sowing, as many native meadow species are drought and heat tolerant and can out compete weeds during the summer (Weaner and Christopher, 2016). In extreme drought seed will cease germinating until sufficient rains occur (Weaner and Christopher, 2016). The Tallgrass Prairie Center warns against seeding after mid-June but affirms spring and fall seeding as viable options (Tallgrass Prairie Center, 2015b). Spring seeding is reported to favor cool-season grasses and some forbs, while a fall seeding will favor those species that require cold stratification for germination (Diboll, 1997; Tallgrass Prairie Center, 2015b). The recommended method of seeding prairie restoration mixes by The Tallgrass Prairie Center is dependent on the ratio of grass to forbs within the mix, with a dormant seeding being suggested for mixes with 50% or greater forb content, and a spring seeding to favor warm-season grasses (Tallgrass Prairie Center 2015b). Grasses can be dormant seeded as well but should have their rates increased by 25% to counter seed loss (Tallgrass Prairie Center, 2015b). A fall seeding is also recommended by The Xerces Society for Invertebrate Conservation (The Xerces Society for Invertebrate Conservation, 2013). Barton et al. (2009) suggest late May through June for the best results, citing spring seeding in Enhancing Delaware Highways research plots yielding consistently better results than fall seedings (Barton et al., 2009). Krouse et al. (2003) working out of the University of Maryland, recommend seeding between September 15^{th} and October 31^{st} for fall seeding and March 15^{th} through April 30^{th} for spring seeding (Krouse, et. al., 2003). Shirley suggests several times for sowing and describes the benefits and challenges they pose. She suggests a spring seeding occur ideally in the first two weeks of June to avoid weed competition, but states that seeding can occur as late as July 15^{th}, provided there is sufficient moisture for 3-4 weeks following sowing (Shirley, 1994). For a fall sowing, she recommends a dormant seeding around November 1^{st}, which has the advantage of natural seed stratification (Shirley, 1994). She also recognizes that a frost seeding is a viable option, up to late March, so long as there is no snow cover, as the freezing and thawing will provide adequate seed to soil contact (Shirley, 1994).

Establishment and Management Practices

Immature meadows require an early input of establishment and management practices but can soon become self-sustaining with occasional management actions required (Weaner and Christopher, 2016). One of the first concerns for a newly seeded meadow is irrigation. Depending upon the size and location of the site, irrigation may be difficult to provide. Weaner and Christopher do not consider irrigation a necessity for seeded meadows; once seeded, the seed will only germinate when sufficient rainfall has occurred (Weaner and Christopher, 2016). If irrigation is required, it should be only to ensure the establishment of viable roots, so the planting remains self-sufficient from that point forward (Weaner and Christopher, 2016).

Although many meadow species are adapted to drought, they still require water in their initial establishment. The Tallgrass Prairie Center recommends a thorough watering of 2.5 to 5 cm every three days during the first growing season, noting that until seedlings have developed beyond the cotyledon stage, they are most susceptible to drought (Tallgrass Prairie Center, 2015c). Shirley recommends thorough irrigation if possible, to ensure good germination, and then advises 1.25 cm of water weekly (supplemental irrigation should occur if rainfall does not provide this level of irrigation) for the first three weeks (Shirley, 1994). The Tallgrass Prairie Center and Shirley are producing this literature for a Midwestern audience. The need for irrigation can be reduced through well-timed sowing to coincide with seasonal rains.

Weeds are a concern in establishing a meadow and must be managed. Weaner and Christopher warn against pulling weeds in most cases, as the soil disturbance will provide the conditions for germination of additional weed seeds. Instead weeds should be cut back to the ground to allow desirable vegetation to eventually outcompete them (Weaner and Christopher, 2016). Zimmerman recommend weeds not be pulled until the second season after the roots of desirable plants have had time to establish and encourages mowing in place of pulling during the first season (Zimmerman, 2010).

Herbicide applications are generally the least labor-intensive. Applications of non-selective herbicide (typically glyphosate) should target weed species when they are most vulnerable (small) and when the likelihood for damage to desirable plants is minimized (Weaner and Christopher, 2016; Tallgrass Prairie Center, 2015c). Targeted applications of broadleaf herbicides can also be utilized as they will remove broadleaf weed species without damaging the grasses within the meadow.

Mowing is another widely recognized method of control that performs the same function as manually cutting back weeds, as well as clearing debris for the next season's growth. Generally, suggested heights for mowing during the first year are between 10 to 30 cm. The Tallgrass Prairie Center recommends 10 to 15 cm in the first year, and 30 cm during the second year of growth. (Tallgrass Prairie Center, 2015c). Krouse et al. (2003) recommends a height of 18 to 25 cm, but only before the new spring growth (Krouse et al., 2003). Ernst Conservation Seeds cautions against dropping below a height of 20 cm during the growing season but suggests cutting to 5 cm before the start of the growing season (Ernst Conservation Seeds, ernstseeds.com). The Xerxes Society recommends routinely mowing establishing meadows to a height of 30 cm (The Xerces Society for Invertebrate Conservation, 2013). Zimmerman advises gradually increasing the mowing height, while reducing frequency; she advises mowing to 15 cm the first year 3-4 times and mowing 2-3 times to a height of 30 cm in the second year (Zimmerman, 2010). Shirley suggests mowing once weeds reach 25 to 30 cm to a height of 5 to 10 cm on the first mowing, and then 15 to 20 cm for successive mowings during the first year (Shirley, 1994). A Tallgrass Prairie Center study of plot establishment across three seed mixes found mowing increased native stem density, doubled the coverage of native plants, and did not change the ratio of grasses to forbs within the mixes (Meissen et al., 2017).

GMS ecosystems, with two-thirds of their biomass occurring below ground, are particularly suited to withstand fires (Gardner, 2011). Many sources advocate for the periodic burning of meadow ecosystems as a rejuvenating practice (Pauly, 1997, Zimmerman, 2010). Meadows can be burnt as early as the second or third year of growth (Pauly, 1997). Typically, controlled burns are carried out during late March through early May (Pauly, 1997). Burns during mid to late spring typically favor warm-season grasses and forbs over cool-season species (Howe, 1995; Zimmerman, 2010). Burns in mid-summer have tended to be more disruptive to succession patterns and favored species that would otherwise be outcompeted such as cool-season grasses and mid-season flowering forbs (Howe, 1995). Though cool-season grasses benefited from mid-summer burnings, it can take several years before forbs that have been subjected to mid-summer burns occur at higher levels than in unburned meadows (Howe, 1995). It remains unclear if fire ecology plays a necessary and rejuvenating role in cool-season grass meadows.

Meadow Ecosystems and Flower Visiting Insects

Threats facing pollinators have been widely publicized. The finer details of many plant-pollinator networks, however, are not as widely researched. Biotic pollination is estimated to account for the pollination of 87.5% of all flowering plant species, and 78% of flowering plants in temperate regions. (Ollerton et al., 2011). Unfortunately, pollinators, both native and domesticated, have been facing serious declines (Potts et al., 2010). Due to the interdependent relationships many plants form with pollinators, declines in plant biodiversity have run parallel with the declines in pollinator populations in some parts of the world (Biesmeijer et al., 2006). In addition to these declines, the demand for biotic pollination dependent crops has increased by nearly 300% from 1960-2006, while there has only been a 90% increase in honey bee colonies during the same time frame (Aizen and Harder, 2009). Bumblebee species have also seen significant declines in species richness in Illinois, likely spurred by the loss of GMS habitat to agricultural development (Grixti et al., 2009).

Plant-pollinator networks are complex. We are just beginning to parse the ways in which changes to landscapes can affect visitation habits (Ferreira et al., 2013). Habitat fragmentation and landscape changes have been shown to affect the diversity and abundance of pollinators and plant communities, but few studies have examined how these losses are impacting overall ecosystem health (Ferreira et al., 2013; Xiao et al., 2016). Changes in pollinator abundance and diversity due to fragmentation tend to lead to a reduction of specialist species and an abundance of generalist species, with some specialists adopting generalist habits (Xiao et al., 2016). Habitat fragmentation has also been shown to change plant phenology (Xiao et al., 2016). Urbanization has been identified as a detrimental change in land usage affecting flower visitor diversity and frequency (Deguines et al., 2012). In woodland habitats, however, localized changes, such as a sunny clearing, or the spread of a valuable floral resource, have been shown to be more significant than landscape level changes to pollinator abundance and diversity (Williams and Winfree, 2013). In examining woodland habitats in urban and suburban forest patches of various sizes, the importance of landscape changes as well as microhabitats was found to be important to forest bee communities (Landsman, et al., 2019). We hope that similar findings can come from small but frequent GMS habitat fragments.

Differences in flower visits and visitors have been observed across prairie types (Robson et al., 2018). Among tall grass, mixed grass, and fescue prairies, flower visits by long-tongued bees were significantly different (Robson et al., 2018). Dipterans also showed significantly different visiting habits between the three meadow types, but not between the fescue and mixed grass prairies. Short-tongued bees did not show any different visitation rates (Robson et al., 2018). It is worth noting that flower types, symmetry, and color were significantly different for at least one of the prairies across the three prairie types (Robson et al., 2018). Homogeneity of forbs across study areas is crucial to isolating visitation habits, as bee diversity has been linked to forb diversity within prairies, but the same was not found with butterfly or syrphid/bombyliid fly diversity (Denning and Foster, 2018).

Restoration settings, due to the designed nature of their plant pallets, can provide the opportunity to isolate the habits of individual flower visitor groups. Bee abundance was found to be affected by bloom diversity and bare ground coverage, while taxonomic diversity was found to be influenced by bloom diversity (Tonietto et al., 2017). The ages of prairie restorations were not shown to affect the diversity of visiting bee species (Tonietto et al., 2017). When species diversity was controlled using a constructed grassland with a limited species pool, visits increased with blossom count as well as plant species richness (Ebeling et al., 2008).

Grasses are frequent and essential parts of designed and restored meadows (Latham and Thorne, 2007; Zimmerman, 2010; Weaner and Christopher, 2016). Most studies that have examined flower visitation and visitor diversity, however, have not treated grasses as a variable of interest, despite grasses forming part of the study area or experiment (Ebeling et al., 2008; Tonietto et al., 2017 Robson et al., 2018). Grassland management via grazing has been shown to affect species abundance. Taller vegetation was correlated with greater hoverfly and beetle diversity and abundance, but did not yield statistically significant differences in bee or butterfly diversity (Sjödin et al., 2008). Given the different growth habits and flowering times of many cool-season grasses, it is possible that the presence of a predominating grass type, could also influence the diversity or abundance of flower visiting insects.

Past Attempts at Creating Wildflower Sod

By replacing the native warm-season grasses that are dominant in meadow mixes with native cool-season grasses, new methods of production may become viable for meadow establishment. There are very few known producers of native wildflower sod in the United States. Of those that do exist, such as Agrecol, (http://www.agrecol.com/, Evansivlle, WI) they utilize greenhouses and various core materials to keep the sod together. In the United Kingdom there are at least two turf producers who have developed a wildflower turf utilizing European natives (Wildflower Turf, Ltd, https://www.wildflowerturf.co.uk, Basingstoke, UK; Wildflower Lawns and Meadows, https://www.wildflowerlawnsandmeadows.com/, Horam, UK).

Weed pressure is an early challenge that can significantly hinder the establishment of constructed and restored meadows (Weaner and Christopher, 2016) and could justify the increased labor of developing wildflower sod. Production of sod allows for the opportunity for post-rehabilitation differences of plant communities to be worked out in more controlled cultivation conditions prior to installation (Stott et al., 2010). Sod has also been shown to reduce weed seed germination and help prevent erosion (Caltrans, 2004), two factors that can greatly inhibit the establishment of turf. When using slower growing native species, the window of time during which erosion and weed pressure can inhibit establishment increases. Sodding also enables the ability to mix different methods of weed control. Pre-emergent herbicides have been used with little to no effect on the successful installation of putting green sod when applied at normal rates (Bingham and Schmidt, 1983). Whether this practice could be translated to a polyculture wildflower sod requires further study.

Despite the lack of available options, there is market interest for a native wildflower sod. Focus groups were used to determine the market viability of wildflower sod amongst homeowners and landscape professionals (Barton et al., 1996). Weed pressure was one of the main concerns of both homeowners and landscape professionals (Barton et al., 1996). The species that were present within the wildflower sod were primarily non-native annuals (Barton, University of Delaware PLSC, personal communication). The article claimed that wildflower sod production problems have been overcome (Barton et al., 1996), yet there are presently no providers of wildflower sod within Delaware, or the larger Mid-Atlantic region.

Wildflower sod development has been documented with articles published detailing various stages of wildflower sod production species selection (Johnson and Whitwell, 1997), soil types (O'Brien and Barker, 1997), and relevant patents that have been granted by the US Patent and Trademark Office. A patent was first granted for the indoor and outdoor production of wildflower sod utilizing a porous synthetic membrane and a planting medium in 1987 (Milstein, 1987). Another patent was granted in 1991 that utilized nylon sod reinforcement within a growing medium to promote the entangling of roots to form a sod mat suitable for wildflower production among other plant types (Molnar, 1991). Neither patent seems to have yielded any lasting investment in the products.

Preliminary trials of wildflower sod have utilized species that lack taproots (Johnson and Whitwell, 1997). Given the depth of roots common to many GMS plants (USDA-NRCS, 2004), this considerably reduces the number of viable species for wildflower sod production. Still, several species have been identified as suitable for sod production (Johnson and Whitwell, 1997); however, these species were not being used as part of a mix.

One method that has proven useful in the harvest and production of sod is growing on plastic (Cisar and Snyder, 1992). Use of a fertilized compost-based growing media over a sheet of plastic, reduced the production time of several warm-season grass sod species (Cisar and Snyder, 1992). Sod grown over plastic also transplanted faster, developed greater root mass faster, and had root mass similar to that of field grown sod at the time of harvest (Cisar and Snyder, 1992). Additionally, bermudagrass sod grown on plastic, under the Game On! Grass brand of Carolina Green Corp. (Fairview, NC), was found to have greater tensile strength than conventionally produced field grown bermudagrass of the same cultivar (Penn State Center for Sports Surface Research, 2014). The plastic grown bermudagrass was over 1 cm thicker at the time of testing tensile strength but was also able to out-perform thicker grown Kentucky bluegrass sod (Penn State Center for Sports Surface Research, 2014). The proven success of growing sod over a plastic barrier in sports field turf production shows promise for wildflower sod. Lateral root concentration could be increased, thus making deeper rooted (USDA-NRCS, 2004) meadow plants easier to harvest without significant disturbance when grown as a sod.

Growing overtop of plastic was used in a wildflower sod trial with a 5 cm depth of various composts but many of the species utilized in this trial were not native and were predominantly annuals (O'Brien and Barker, 1997). Utilizing plastic should prevent the majority of weed seed from contaminating the wildflower sod during production. A fully rooted mat of wildflower sod, when transplanted, will hopefully reduce weed pressure due to the already established competitive root zone within the sod.

Concluding Remarks

The experiments herein were designed with the considerations of this literature review in mind. Seed mixes, seeding rates, site selection, preparation, management, and sowing methods were all adopted from the recommendations outlined within this literature review. The experiments aim to quantify several aspects of the literature, namely the establishment of meadows from seed and the ability for the species within the mixes to endure and alter the composition of the meadow in its early formative years.

Chapter 2

EVALUATING COOL-SEASON GRASS MEADOW ESTABLISHMENT

Research Objectives and Hypotheses

The aims of this chapter are to provide a quantitative basis for the establishment of cool-season grass dominant meadows in the Mid-Atlantic utilizing two different seed mixes, three seeding rates, and two different sowing times. We compare the rate of germination and coverage of grasses and forbs between a spring and fall sowing, to determine during which season meadow plantings establish more successfully. Species richness was also recorded throughout the growing season. We hypothesize that cool-season grasses can provide an acceptable base for meadow seed mixes and that spring and fall sowing are viable, but that spring will favor forb establishment, while fall favors cool-season grass establishment in the Mid-Atlantic. We also expect that regardless of sowing time, increasing the rate of seed will increase early percent ground cover, but at the expense of species richness over time.

Differences in species composition have been reported through inventories of species present within different treatments and estimation of the percentage of coverage that each species provides within each plot. We suspect that plots that were under or over seeded will be less diverse. Differences in the abundance and types of spontaneous vegetation that appear between the two different times of sowing have also been reported, as a successful establishment also depends on desirable species outcompeting weeds and providing space for recolonizing native vegetation of value. We predict that weed pressure will decrease with a fall sowing due to establishment of cool-season grasses in the fall before warm-season weeds are able to gain a foothold.

Materials and Methods

Plant Selection

Plant selections were made with the following factors as guiding principles:

1. **Native status:** Only plants native to the Mid-Atlantic were selected. Plants were determined to be native using the USDA PLANTS Database (USDA-NRCS, https://plants.sc.egov.usda.gov), and The Flora of North America (Flora of North America Editorial Committee, http://beta.floranorthamerica.org/Main_Page). For the purposes of this project the Mid-Atlantic included Delaware, Maryland, New Jersey, New York, Pennsylvania, and Virginia. Plants did not need to be native to all the Mid-Atlantic states to be included.

2. **Ecological impact:** Selected plants had to serve some purpose within the landscape, with many plants fulfilling more than one ecological function. Ecological functions taken into consideration were pollinator food sources, natural weed suppression, nitrogen fixation, other wildlife food sources, and diversity in plant morphology. Similarly, plants were selected that could be expected to adapt reasonably well to the site conditions.

3. **Size:** Species were selected with an intended mature size reaching approximately 61 cm of herbaceous growth, with inflorescences receiving less strict size limitations. Some taller species were permitted in lower proportions of the mix in the interest of architectural diversity and creating stronger flower visitor communities.

4. **Diversity:** Plants were selected in an attempt to maximize diversity. Diversity of plant material was further emphasized within the selection of forbs for the sake of flower visitor health. Similarly, a diversity of forbs ensured that successive flowering times would be more reliable in supporting season-long pollinator foraging and horticultural interest.

Meadow Seed mixes

Two different seed mixes were tested: one fescue dominant with *Festuca rubra ssp. rubra* and another dominated by *Agrostis perennans* (Walter) Tuck., a bentgrass species (Tables 2 and 3). Between the two mixes, only the cool-season grasses differ. Within the cool-season grass portions of these mixes, the fescue dominant mix tended toward more rhizomatous and stoloniferous cool-season grass species, with 40% of the total mix being comprised of grasses that commonly have rhizomatous or stoloniferous habits. The cool-season grass portion of the bentgrass mix was primarily composed of bunch forming grasses, with 9% of the mix being comprised of species that tend toward stoloniferous habits. Forb and warm-season grass species and rates are identical in both mixes. Both the fescue mix and the bentgrass mix were sown at three rates: 0.5x, 1x, and 2x density. A 1x density is the suggested seeding rate for full coverage based upon the calculations enumerated in the prior chapter by the NRCS (Houck, 2009). Each mix was sown within the spring and fall. Four replications of each treatment were applied for a total of 48 plots. A randomized complete block design was used for the spring and fall sown plots.

Though cool-season grasses are dominant in the proposed seed mixes, warm-season grasses are included, but at very low rates. Warm-season grasses were included for the promotion of species diversity and structural interest in the late fall through winter seasons. Several leguminous forbs were chosen due to their nitrogen fixing abilities.

The seed mixes developed for this research are two of countless possible mixes and reflect the specific constraints of this project. The seed mixes developed are generalist mixes for this region based on species that are typically readily available. A mix that could accommodate the possible conditions of several sites, as well as standing the greatest chance of establishing and surviving with minimal supplemental irrigation, was designed. Future seed mixes could be developed to accommodate

Table 2 Fescue dominant seed mix: seeding rates of all species within the fescue mix with total weight of PLS per plot.

Species	Common Name	kg PLS per ha	Rate	1x PLS per plot (mg)	1/2x PLS per plot(mg)	2x PLS per plot (mg)
Deschampsia cespitosa	Tufted Hairgrass	2.2	10.00%	89.7	44.9	179.3
Festuca rubra spp. rubra	Creeping Red Fescue	13.5	30.00%	1614.0	807.0	3228.1
Danthonia spicata	Poverty Oatgrass	28.0	10.00%	1120.9	560.4	2241.7
Poa palustris	Fowl Bluegrass	3.4	10.00%	134.5	67.3	269.0
Elymus virginicus	Virginia Wildrye	22.4	5.00%	448.3	224.2	896.7
Asclepias tuberosa	Butterfly Milkweed	11.2	2.00%	89.7	44.9	179.3
Coreopsis lanceolata	Lanceleaf Coreopsis	7.8	2.00%	62.8	31.4	125.5
Rudbeckia hirta	Black-eyed Susan	0.5	1.00%	5.6	2.8	11.2
Echinacea purpurea	Purple Coneflower	13.5	2.00%	107.6	53.8	215.2
Liatris spicata	Dense Blazing Star	11.2	1.00%	44.8	22.4	89.7
Gaillardia pulchella	Indian Blanket	12.0	1.00%	53.8	26.9	107.6
Monarda didyma	Scarlet Beebalm	4.0	0.25%	3.9	2.0	7.8
Monarda fistulosa	Wild Bergamot	4.0	0.25%	3.9	2.0	7.8
Penstemon digitalis	Foxglove Beardtongue	11.2	1.00%	44.8	22.4	89.7
Solidago nemoralis	Gray Goldenrod	11.2	1.00%	44.8	22.4	89.7
Pycnanthemum muticum	Clustered Mountainmint	11.2	0.20%	9.0	4.5	17.9
Agastache foeniculum	Anise Hyssop	11.2	2.00%	89.7	44.9	179.3
Symphyotrichum laeve	Smooth Aster	11.2	3.00%	134.5	67.3	269.0
Tradescantia ohiensis	Ohio Spiderwort	11.2	1.00%	44.8	22.4	89.7
Eupatorium perfoliatum	Common Boneset	11.2	0.50%	22.4	11.2	44.8
Eutrochium purpureum	Joe Pye Weed	11.2	0.50%	22.4	11.2	44.8
Zizia aurea	Golden Alexanders	11.2	2.50%	112.1	56.1	224.2
Viola sororia	Common Blue Violet	11.2	2.50%	112.1	56.1	224.2
Chamaecrista fasciculata	Partridge Pea	3.4	3.30%	44.3	22.1	88.5
Lespedeza capitata	Roundheaded Bush Clover	4.5	1.00%	17.9	9.0	35.9
Baptisia australis	Blue Wild Indigo	11.2	2.00%	89.7	44.9	179.3
Schizachyrium scoparium	Little Bluestem	11.2	2.50%	112.1	56.1	224.2
Sporobolus heterolepis	Prairie Dropseed	6.7	1.50%	40.4	20.2	80.7
Tridens flavus	Purpletop	28.0	1.00%	112.1	56.1	224.2

Table 3 Non-fescue seed mix—seeding rates of all species within the non-fescue mix with total weight of PLS per plot.

Species	Common Name	kg PLS per ha	Rate	1x PLS per plot (mg)	1/2x PLS per plot (mg)	2x PLS per plot (mg)
Deschampsia cespitosa	Tufted Hairgrass	2.2	15.00%	134.5	67.3	269.0
Danthonia spicata	Poverty Oatgrass	28.0	20.00%	2241.7	1120.9	4483.4
Elymus trachycaulus	Slender Wheatgrass	6.7	5.00%	134.5	67.3	269.0
Poa palustris	Fowl Bluegrass	3.4	9.00%	121.1	60.5	242.1
Agrostis perennans	Upland Bentgrass	22.4	11.00%	986.4	493.2	1972.7
Elymus virginicus	Virginia Wildrye	22.4	5.00%	448.3	224.2	896.7
Asclepias tuberosa	Butterfly Milkweed	11.2	2.00%	89.7	44.9	179.3
Coreopsis lanceolata	Lanceleaf Coreopsis	7.8	2.00%	62.8	31.4	125.5
Rudbeckia hirta	Black-eyed Susan	0.5	1.00%	5.6	2.8	11.2
Echinacea purpurea	Purple Coneflower	13.5	2.00%	107.6	53.8	215.2
Liatris spicata	Dense Blazing Star	11.2	1.00%	44.8	22.4	89.7
Gaillardia pulchella	Indian Blanket	12.0	1.00%	53.8	26.9	107.6
Monarda didyma	Scarlet Beebalm	4.0	0.25%	3.9	2.0	7.8
Monarda fistulosa	Wild Bergamot	4.0	0.25%	3.9	2.0	7.8
Penstemon digitalis	Foxglove Beardtongue	11.2	1.00%	44.8	22.4	89.7
Solidago nemoralis	Gray Goldenrod	11.2	1.00%	44.8	22.4	89.7
Pycnanthemum muticum	Clustered Mountainmint	11.2	0.20%	9.0	4.5	17.9
Agastache foeniculum	Anise Hyssop	11.2	2.00%	89.7	44.9	179.3
Symphyotrichum laeve	Smooth Aster	11.2	3.00%	134.5	67.3	269.0
Tradescantia ohiensis	Ohio Spiderwort	11.2	1.00%	44.8	22.4	89.7
Eupatorium perfoliatum	Common Boneset	11.2	0.50%	22.4	11.2	44.8
Eutrochium purpureum	Joe Pye Weed	11.2	0.50%	22.4	11.2	44.8
Zizia aurea	Golden Alexanders	11.2	2.50%	112.1	56.1	224.2
Viola sororia	Common Blue Violet	11.2	2.50%	112.1	56.1	224.2
Chamaecrista fasciculata	Partridge Pea	3.4	3.30%	44.3	22.1	88.5
Lespedeza capitata	Roundheaded Bush Clover	4.5	1.00%	17.9	9.0	35.9
Baptisia australis	Blue Wild Indigo	11.2	2.00%	89.7	44.9	179.3
Schizachyrium scoparium	Little Bluestem	11.2	2.50%	112.1	56.1	224.2
Sporobolus heterolepis	Prairie Dropseed	6.7	1.50%	40.4	20.2	80.7
Tridens flavus	Purpletop	28.0	1.00%	112.1	56.1	224.2

different cultural conditions, serve particular ecological purposes or allow varying levels of novelty.

Calculating Seeding Rates

Seeding rates were calculated by taking the seeding rate in pounds of pure live seed (PLS) per acre to create a predicted adequate stand and multiplying it by the desired species representation within the mix. This is the method recommended by the NRCS (Houck, 2009). When recommended seeding rates were expressed as a range, the highest seeding rate was used to ensure dense coverage to out-compete weed seeds that may germinate and to compensate for the fact that seed was sown through broadcast seeding (for which higher rates are typically suggested). Some interpretive liberties were taken with the seeding rates of species that did not have recommended seeding rates. There were several instances where the rate of seed required for full coverage was unknown. This was most often the case with forb species that are not produced in bulk for economic purposes or do not have widespread use as a reclamation species in a monostand. In instances where the rates of seeds were not specifically known, a rate of 11.2 kg per hectare was used for forb species, as this is the recommended high seeding rate of most forb mixes (Barton, University of Delaware-PLSC; personal communication with Ernst Conservation Seeds). When multiple sources provided conflicting seeding rates, in which there was little overlap, the rate of seed was determined using past experiences of the author regarding germination of these species. In some cases, similar species within the genus were used to determine the seeding rate.

Site Preparation

Plots were 2 x 2 meters. Spring sown plots were prepared with three applications of glyphosate (41% glyphosate, Ranger Pro, Monsanto, St. Louis, MO) applied in a 2% solution on February 20th, March 1st, and May 3rd, 2018. Three applications were used due to limited uptake during the first application. Applications of glyphosate (41% glyphosate, Ranger Pro, Monsanto, St. Louis, MO) for the fall sowing were applied in a 2% solution on August 28th and September 5th. A 51 cm mulch border was maintained on all sides of each individual plot to ensure plots remained distinguishable from one another, for access during data collection, as well as to ensure debris from the mowing of the surrounding turf did not become displaced into the outermost plots. Prior to sowing, a verticutter was used on the plots to eliminate a majority of the remaining turf thatch. Thatch was removed from the seed beds.

A soil test, sampled to 10 cm, was conducted prior to sowing. Mean pH levels ranged from 7.0 to 7.2. Organic content ranged from 6.2% to 7.3%. The soil was classified as sandy loam urban soil due to recent construction and fill next to the Fischer Greenhouse Laboratory.

Sowing

Seed was sown using sawdust (Pine View Trucking Inc., Nottingham, PA) as a carrier and a mulch. Seed was mixed in a wheelbarrow with enough sawdust to create a 1.2 cm thick cover over the seed bed. The sawdust and seed mixtures were applied to the open plots and spread evenly using a rake. The sawdust was used as a mulch to retain moisture and allow enough light to promote germination, but still inhibit the germination and spread of weed seeds that may be present in the soil.

Spring plots were sown at the University of Delaware Botanic Garden on May 9. Fall plots were sown on October 2. All plots received an application of fertilizer two weeks after sowing at a rate of 9.8 g per m^2 in order to counteract the nitrogen-poor sawdust. The fertilizer nutrient analysis was 25-0-11, with 11.25% slowly available urea nitrogen from polymer coated sulfur coated urea and 2% iron, manufactured by Helena Chemical Company (Collierville, TN) under the brand Pro-Mate.

Site Monitoring and Data Collection

Rates of germination were examined by taking three biweekly random samples using a 20 x 20 cm grid and counting the number of seedlings present (Tall Grass Prairie Center, 2015d). This data was collected over 12 weeks. Data collection for the spring sown plots began two weeks after the date of sowing and finished August 5th. Plots that were sown in the fall had germination data collected from two weeks after they were sown until the end of October totaling two collections, received a natural stratification period during the winter, then had the remaining 8 weeks of data collected beginning April 15th, when conditions were seasonably favorable for germination to occur again. Data was used to calculate the mean number of seedlings per 20 x 20 cm grid. The mean of the six samples was calculated and multiplied by 100 to estimate the overall number of seedlings per plot. The overall number of seedlings per plot was divided by the estimated total number of seeds within the plot to approximate the overall rate of germination and seedling survival. An assessment of the community composition by percent coverage of each species in the spring and fall sown plots was carried out within 14 days of the final germination datapoint.

Species of spontaneous vegetation were recorded with a linear 1-5 scale where 5 is extremely prevalent in most plots, and 1 is a negligible presence in only a few plots (Vanhala et al., 2004). Exotic weeds and spontaneous native plants that appeared within the plots were separated to see how natural succession processes compared with exotic weed pressure. The linear scale utilized here alongside the origins of the spontaneous vegetation is meant to be descriptive more so than communicate statistically significant data.

Species richness was recorded throughout the season. Any species from the mix that appeared during that growing season was used to calculate the total species richness. Monthly assessments of coverage from each species in the mix appearing within the plots was conducted beginning in April 2019 and concluding in October 2019. During the first year of the spring plots, coverage was estimated in July and September to provide peak and end of season comparisons for the first year of establishment for the fall sowing, and the second year of the spring sowing. Assessments of coverage were conducted by taking a photo of each plot from approximately 1.2 m above the estimated average vegetation height. This image was then cropped to only include the vegetation within the plot and had a 10 x 10 grid placed over it using Proportion Grid Maker (Vavatch Software, 2016). The grid was proportional to the dimensions of the photo. Each species occurring was counted. Species below 0.5% coverage were excluded. Aggregate values of coverage were calculated for all forb species, all grass species, and the total percentage of open space or weeds that occurred.

Figure 1 Example of image used to quantify the coverage of each occurring species from the seed mix.

The total percent coverage was used to calculate cardinal values of abundance to determine Simpson's Diversity Index (Morris et al., 2014) for the month of July. The month of July was selected as being of primary interest as this is when most insect visitations occurred. Simpson's Diversity Index considers the total richness and abundance within each plot and provides a value between 0 and 1 where 0 is no diversity and 1 is infinite diversity. The cardinal abundance values used were between 0 and 9, where 0 is 0% coverage, 1 is 0.5% to 10% coverage, 2 is 10.5% to 20%

coverage, and so on. Data was analyzed using a three-factor Analysis of Variance (ANOVA) in JMP Version 14 (SAS Institute, Inc., Cary, NC, 1989-2020) at $\alpha=0.05$.

Site Maintenance

In the interest of ensuring the best chance of establishment and that the plots within the University of Delaware Botanic Garden were kept presentable weeds were regularly removed in the least disruptive fashion. Depending on the size and morphology of the weeds to be removed, weeds were either pulled when it would not disrupt neighboring seedlings or cut to the crown. In their first year, the fall sown plots had an extremely high amount of crabgrass competition. A single application of glyphosate (41% glyphosate, Ranger Pro, Monsanto, St. Louis, MO) in a 2% solution by spot treatment was made to ensure the future success of the fall sown plots. In a real-world application of these seed mixes, potentially at a larger scale, weed management in this fashion would not be feasible. A larger application of these mixes would require different management practices.

Results

Germination and Coverage

The total percentage of germinating plants was affected by three variables: season of sowing, seeding rate, and seed mix. There was significant interaction between each of these variables, but the interaction of all three variables together was not significant ($p=0.0913$). The season of sowing ($p<0.0001$), rate of seed ($p<0.0001$) and the mix ($p<0.0001$) all had a strong effect on the percent germination. The fall sowing resulted in higher levels of germination, as did the 0.5x rate (the 1x and 2x rates were not significantly different from each other), and the fescue mix resulted in higher levels of germination.

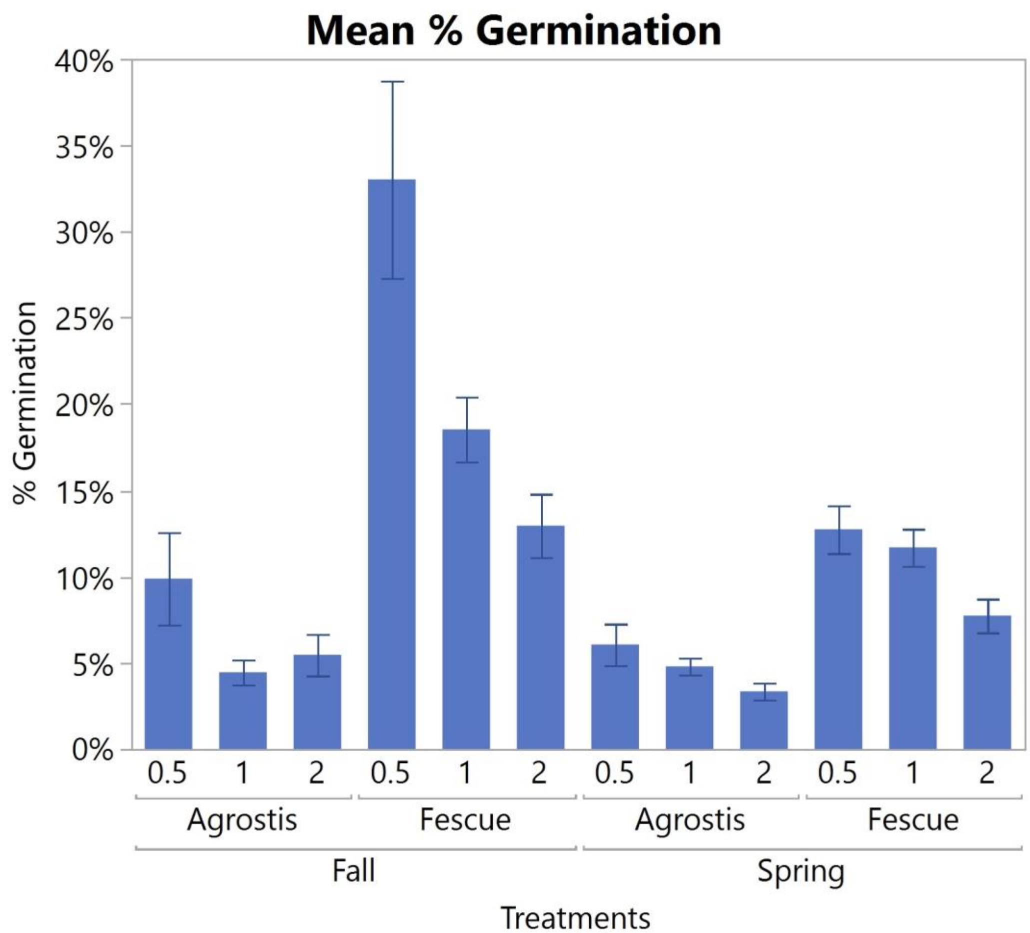


Figure 2 Mean % germination of all treatments. Bars represent one standard error from the mean.

Interaction was noted between the season of sowing*rate (*p*=0.009), the season of sowing*mix (*p*=0.0009), and the mix*rate (*p*=0.0195). The season of sowing*rate resulted in the fall sown 0.5x rate differing from all the other rates and sowing times. The fall 1x sowing differed from the spring 2x sowing, but there was no difference between any of the other combinations of season and rate. The interaction between the season of sowing*mix indicated differences between the fall sown fescue mix and spring sown fescue mix, which both differed from the spring and fall sown bentgrass mixes. The spring and fall sown bentgrass mixes did not differ from one another. The interaction between the rate*mix yielded a *p*-value of *p*=0.0195. The 0.5x rate of the fescue was different from all the other rate*mix combinations with the 1x fescue mix differing from the 2x fescue mix and the 0.5x bentgrass mix. The 1x and 2x bentgrass mixes were different from the 2x fescue mix, but not the 0.5x bentgrass mix.

Significant differences were present in the grass and forb coverage of plots at the time of the final germination estimates. Significant differences were found in the amount of empty space left available in each plot as well. The percentage of grass coverage was strongly influenced by the season in which seeds were sown ($p<0.0001$). After 12 weeks, spring sown plots had a mean grass coverage of 2.4%, while fall sown plots had mean grass coverage of 36.6%.

Forb coverage was impacted by the season of sowing ($p<0.0001$), seeding rate ($p<0.0001$), and their interaction ($p<0.0001$). Mean forb cover was 65.1% in the spring sown plots, and 13.5% in the fall sown plots. The 2x rate also had significantly higher forb coverage than the 1x and 0.5x rates. Differences in coverage between the 1x and 0.5x rate were not statistically significant. When rate and season of sowing were taken together, there were statistically significant differences between all rates in the spring sowing. The highest level of forb coverage was at the 2x rate, followed by the 1x rate, and the lowest coverage at the 0.5x rate, which was still different from all of the rates in the fall sowing, which resulted in no difference between the three rates.

The spring sowing had significantly less open space at the 12-week mark than the fall sowing (p=0.0104), with the fall sown plots having a mean level of unoccupied space of 49.8% and the spring sown plots having a mean level of 32.6%. Rate also affected the amount of unoccupied space (p=0.0003). The 2x rate resulted in significantly less open space than the 0.5x and 1x rates. The 0.5x and 1x rates did not differ from one another.

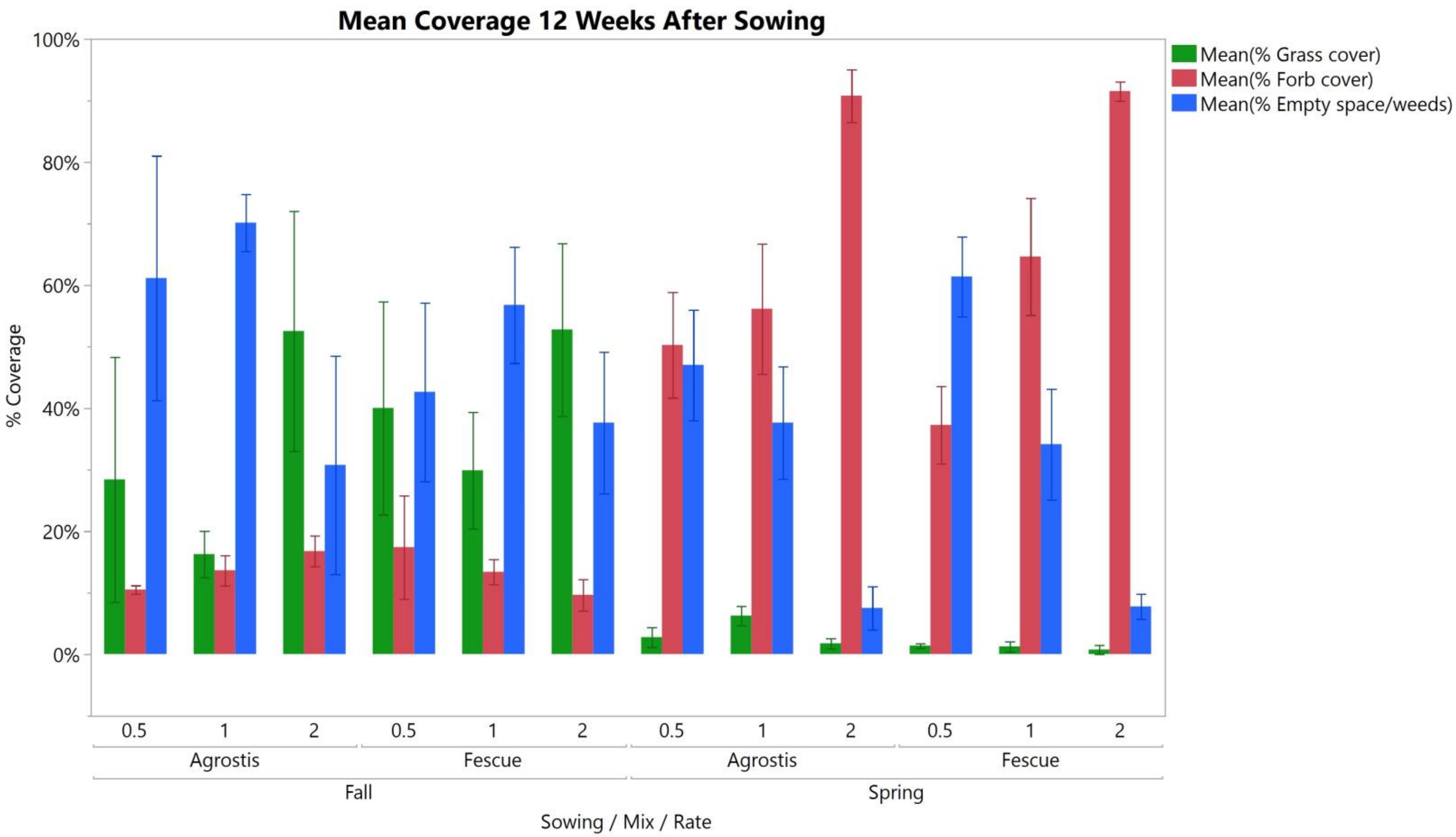


Figure 3 Mean percent coverage of grasses, forbs, and unoccupied space at the end of germination observations. Bars represent one standard error of the mean.

Spontaneous Vegetation

Our findings have affirmed existing diagnoses of spontaneous vegetation pressure in meadow installations (Table 4). Spontaneous vegetation in the spring sowing was found to be significantly less in the second year (p=0.0191). The number of native taxa encountered in the first year of the spring sown plots was 17, and the number of introduced taxa encountered was 21. In the second year the number of native taxa encountered decreased to 9, while the number of introduced taxa increased to 24, but the difference in native and introduced taxa ratings was not statistically significant (p=0.1527). Though spontaneous vegetation pressure was reduced, the higher level of taxa can be attributed to sampling period of the second year including cool-season annual species present in the earlier spring months. The May sowing date precluded these species from being counted in the first year.

Spontaneous vegetation pressure was significantly lower in the first year of the spring sowing (p=0.0068) when compared with the first year of the fall sowing. A total of 22 native taxa and 42 introduced taxa were encountered in the fall sown plots. The relationship between the ratings of the native and introduced taxa were not statistically significant (p=0.5984) indicating that native species were no less likely to colonize the recently sown meadows than introduced species. Cool-season annual weeds were again precluded from this data given the sowing time for the spring sown plots.

Table 4 Complete list of all occurring species that were not part of the seed mix in the first year of the spring plots (Spring Y1), second year of the spring plots (Spring Y2), and the first year of the fall plots (Fall Y1). Ratings are based on the corresponding qualifiers: 0) species not encountered, 1) species has a negligible presence, 2) species occurs infrequently, 3) species is regularly occurring, 4) species is frequently occurring, but is not very competitive with intentionally sown plants, 5) species occurs frequently and is a significant competitor with intentionally sown plants.

Scientific Name	**Common Name**	**Spring Y1**	**Spring Y2**	**Fall Y1**	**Status**
Abutilon theophrasti	Velvetleaf	3	0	5	Introduced
Acer rubrum	Red Maple	1	0	0	Native
Ageratina altissima	White Snakeroot	0	0	3	Native
Ailanthus altissima	Tree of Heaven	1	0	0	Introduced
Allium vineale	Wild Garlic	0	0	2	Introduced
Amaranthus albus	Prostrate Pigweed	0	0	1	Introduced
Amaranthus retroflexus	Pigweed	3	0	2	Native
Barbarea vulgaris	Yellow Rocket	2	2	2	Introduced
Bromus sp.	Brome	0	2	0	Introduced
Cardamine hirsuta	Hairy Bittercress	0	2	1	Introduced
Cerastium vulgatum	Mouseear Chickweed	0	3	3	Introduced
Chenopodium album	Common Lambsquarters	3	1	3	Introduced
Chrysanthemum leucanthemum	Oxeye Daisy	0	0	1	Introduced
Cichorium intybus	Chicory	3	0	3	Introduced
Conyza canadensis	Canadian Horseweed	2	2	3	Native
Cynodon dactylon	Bermudagrass	2	2	0	Introduced

Scientific Name	Common Name	Spring Y1	Spring Y2	Fall Y1	Status
Cyperus esculentus	Yellow Nutsedge	5	1	2	Introduced
Dactylis glomerata	Orchardgrass	0	1	4	Introduced
Daucus carota	Wild Carrot	1	0	0	Introduced
Digitaria ischaemum	Smooth Crabgrass	0	3	5	Introduced
Digitaria sanguinalis	Large Crabgrass	2	3	5	Introduced
Duchesnea indica	Mock Strawberry	0	1	0	Native
Eleusine indica	Indian Goosegrass	0	0	2	Introduced
Erechtites hieraciifolius	American Burnweed	3	1	4	Native
Erigeron annuus	Fleabane	3	3	5	Native
Eupatorium sp.	Bonesets	0	0	1	Native
Euphorbia maculata	Spotted Spurge	4	0	1	Native
Festuca arundinaceae	Tall Fescue	2	2	2	Introduced
Fragaria virginiana	Wild Strawberry	1	3	3	Native
Gamochaeta purpurea	Purple Cudweed	1	0	0	Native
Geranium carolinianum	Carolina Cranesbill	1	0	2	Native
Geum canadense	White Avens	0	1	0	Native
Koelreutaria paniculata	Golden Raintree	0	0	2	Introduced
Lagerstromia indica	Crepe Myrtle	0	0	2	Introduced
Lamium amplexicaule	Henbit	0	1	2	Introduced
Latuca seriola	Prickly Lettuce	2	0	2	Introduced
Matricaria discoidea	Pineappleweed	0	0	1	Introduced
Medicago lupulina	Black Medic	0	0	2	Introduced
Mollugo verticillata	Carpetweed	4	0	2	Native
Morus alba	White Mulberry	2	0	0	Introduced
Oxalis cornculata	Creeping Woodsorrel	2	0	3	Native

Scientific Name	Common Name	Spring Y1	Spring Y2	Fall Y1	Status
Oxalis stricta	Yellow Woodsorrel	3	3	3	Native
Oxybasis glauca	Oak-leaved Goosefoot	3	0	2	Introduced
Panicum capillare	Witchgrass	2	0	0	Native
Panicum dichotomiflorum	Fall Panicum	3	0	0	Native
Persicaria tinctoria	Japanese Indigo	0	1	3	Introduced
Petunia axillaris	Wild White Petunia	1	0	0	Introduced
Phleum pratense	Timothy Grass	0	0	1	Introduced
Phytolacca americana	Common Pokeweed	2	0	3	Native
Plantago lanceolata	Buckhorn Plantain	2	0	0	Introduced
Poa annua	Annual Bluegrass	0	2	5	Introduced
Polygonum pensylvanicum	Pennsylvania Smartweed	0	0	3	Native
Portulaca oleracea	Common Purslane	5	0	2	Introduced
Potentilla recta	Sulfur Cinquefoil	0	0	2	Introduced
Ranunculus acris	Hairy Buttercup	0	1	2	Introduced
Ranunculus bulbosus	Bulbous Buttercup	0	0	2	Introduced
Rumex acetosella	Red Sorrel	1	0	0	Introduced
Salix nigra	Black Willow	0	0	2	Native
Senecio vulgaris	Common Groundsel	3	1	3	Introduced
Setaria faberi	Japanese bristlegrass	1	0	3	Introduced
Setaria glauca	Yellow Foxtail	3	0	2	Introduced
Silene armeria	Sweet William Catchfly	0	0	1	Introduced
Solanum ptycanthum	Eastern Black Nightshade	3	0	2	Native
Solidago canadensis	Canada Goldenrod	0	0	3	Native
Solidago juncea	Early Goldenrod	1	0	0	Native

Scientific Name	Common Name	Spring Y1	Spring Y2	Fall Y1	Status
Sonchus oleraceus	Annual Sowthistle	1	2	3	Introduced
Stellaria media	Common Chickweed	0	4	4	Introduced
Symphyotrichum ericoides	White Heath Aster	0	0	1	Native
Symphyotrichum lanceolatum	Panicled Aster	0	1	1	Native
Symphyotrichum pilosum	Hairy White Oldfield Aster	0	2	3	Native
Tanacetum parthenium	Feverfew	0	0	2	Introduced
Taraxacum officinale	Dandelion	3	2	3	Introduced
Thlaspi arvense	Field Pennycress	0	0	1	Introduced
Tragopogon dubius	Yellow Salsify	0	1	0	Introduced
Trifolium repens	White Clover	0	1	1	Introduced
Trifolium pratense	Red Clover	3	1	2	Introduced
Verbena stricta	Hoary Vervain	0	0	1	Native
Veronica serpyllifolia	Thymeleaf Speedwell	0	2	0	Introduced
Veronica spp.	Common Speedwell	0	3	2	Introduced
Viola arvensis	European Field Pansy	0	0	1	Introduced
Vitis riparia	Riverbank Grape	0	0	1	Native

Community Composition

Species richness in the first year of the spring sown plots and the first year of the fall sown plots was found to be impacted by the season of sowing as well as the rate of seed. The proportion of species encountered through the first year of each sowing differed greatly ($p<0.0001$). The spring sowing had a mean value of 51.7% of the species occurring, while the fall sowing had a mean value of 35.6% (Figure 4). The rate was also a significant factor ($p=0.0402$), with richness declining as the seeding rate declined. The 2x rate was found to differ significantly from the 0.5x rate, but the 1x rate did not differ from either the 0.5x or the 2x rates.

When comparing species richness between the first and second year of the spring sowing, only the seeding rate was found to impact species richness ($p=0.007$). Richness followed the same trend with species richness declining with the seeding rate. The 2x rate was significantly greater than the 0.5x rate, but the 1x rate was not significantly different from the 0.5x or 2x rates.

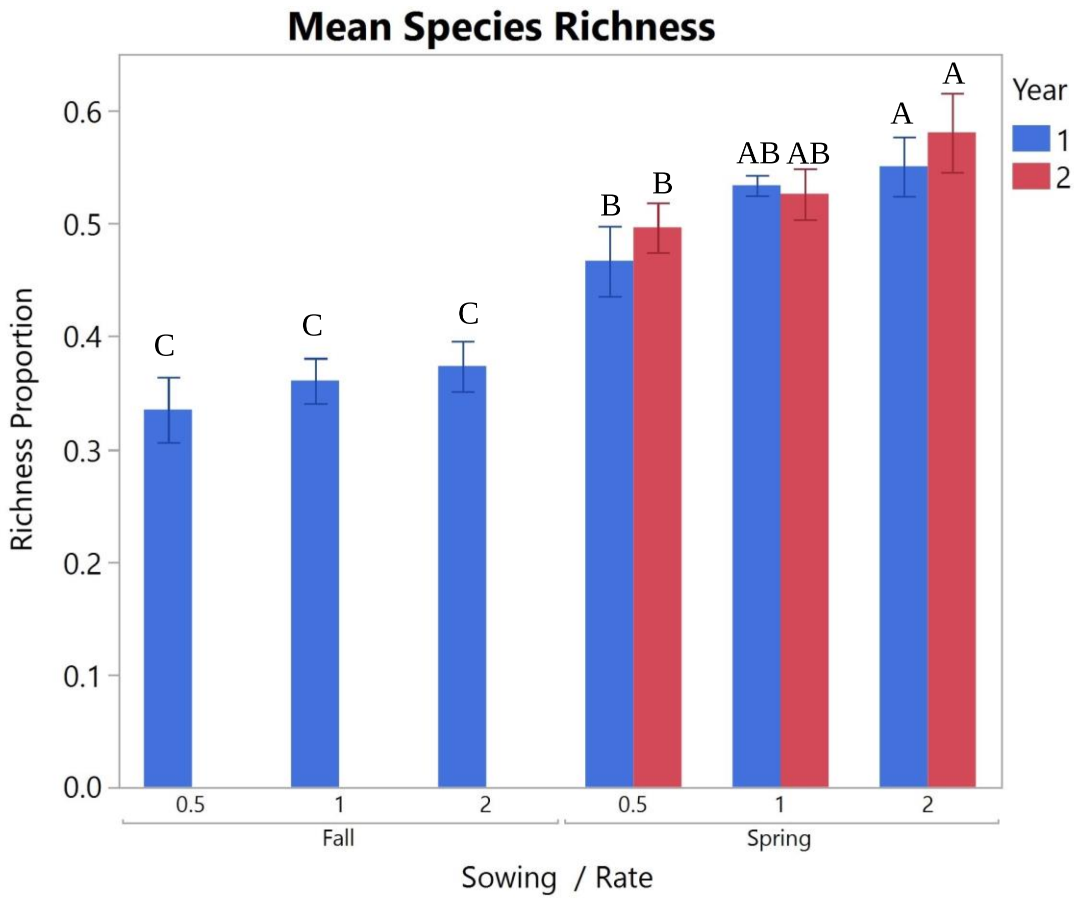


Figure 4 Mean species richness between sowing times, sowing rates, and the year of observation. Bars represent one standard error of the mean.

Forbs accounted for nearly 2/3s of the total species of both mixes. Regressing forb richness to the total richness yields an R^2 value of 0.9, indicating that forb richness was the major driver of overall richness (Figure 5). Forb richness in the first year of the spring and fall sowing had the same factors of significance as overall species richness with the season of sowing having the greatest effect (p<0.0001) and the rate having a more pronounced effect than it did in the overall species richness (p=0.0227) (Figure 4).

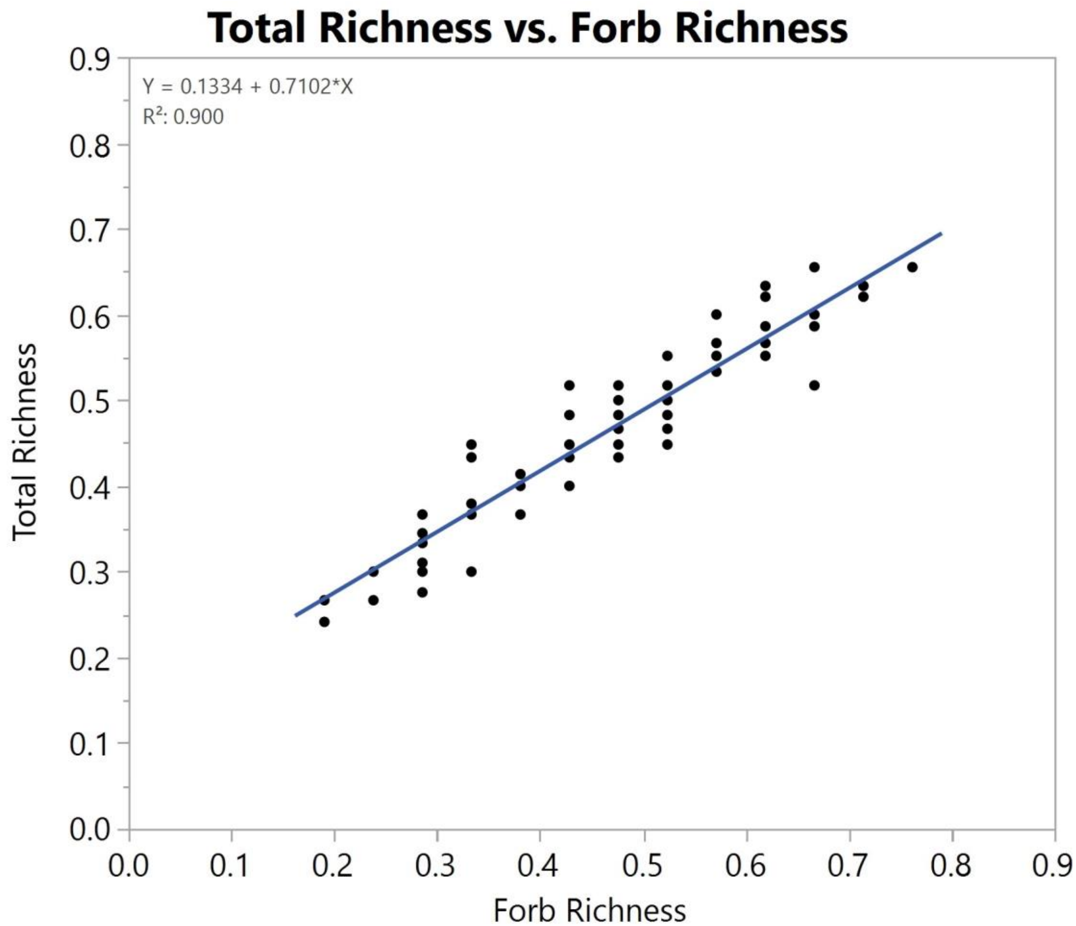


Figure 5 Regression plot of total richness to forb richness.

Simpson's Diversity Index indicated no difference in the diversity of the first-year fall and spring sown plots (p=0.4123) during the month of July. The first and second years of the spring also showed no difference in Simpson's Diversity Index for the month of July (p=0.6469). The lack of significance in Simpson's Diversity Index indicates that, despite the differences in species richness, the total abundance of the species within the plots smooths out these differences. The mean value for 1-D, the measurement of diversity on a 0 to 1 scale in Simpson's Index of Diversity, was 0.901

for the first year spring sown plot, 0.907 for the second year of the spring sown plot, and 0.863 for the first year of the fall sowing. These values indicate a high degree of diversity across all plots.

Discussion

Despite differences in germination rates, all mixes, at all rates, and at all sowing times produced, when hand-weeded, viable meadows. Mean germination rates varied from 3% to 33%, with most falling near the 10% field germination typical of prairie restorations (Pellish et al., 2017). Differences in germination and types of coverage were driven by the time of sowing in all cases. Unlike with warm-season grass dominant meadows where germination of both forbs and grasses typically will not occur until soil temperatures begin to reach 18˚C (Langell et al., 1998), cool-season grass meadow mixes can have highly favorable germination conditions for forbs or grass types depending upon the time of sowing. This information is not new and conforms to commonly distributed recommendations of establishing turf using cool-season grasses but does add new considerations for the establishment of meadow mixes by seed for the Mid-Atlantic region. The spring plots had such low levels of cool season grass germination when they were initially sown, that they required the cool-season grass components of their mixes to be resown in the fall in order to have a reasonable level of cool-season grass coverage for the insect visitation portion of this experiment. After resowing, their grass coverage was still lower, but not significantly different than the grass coverage of the fall sown plots in the month of June (p=0.0568). This affirms that it is indeed the fall sowing season exerting the greatest impact over grass coverage. Lower coverage is expected for the resown grasses as the resown grasses had to compete with the basal foliage of already established forbs.

The lower, but not significantly different coverage of grasses also tells us that it is unlikely the additional grass coverage was due to ungerminated seeds from the initial sowing. In the spring sowing, the opposite occurred, with forbs being strongly favored and establishing with much greater coverage. Forb establishment is likely a reason for a greater percentage of unoccupied space in the fall sown plots, as a single forb seedling will usually cover far more of the surface area than a single grass seedling. Open space in a meadow planting is space that can be taken over by adventitious species. Many weed species occupy this same niche and will exploit open space in a meadow. In successful meadow establishment, open space is claimed early on by rapidly establishing annual or short-lived perennials within the seed mix that eventually give way to longer lived species. To observe and record that the fall sown plots also experienced higher levels of spontaneous vegetation pressure is not surprising given they had a greater level of open space. Further research should be conducted to see whether certain leaf morphologies or plant structures differ in the quality of coverage provided by increasing shading and thus preventing spontaneous vegetation.

The fescue mix tended to establish with higher rates of germination. Several differences between the rates of cool-season grass species may explain some of the disparity in germination between the fescue and bentgrass mix. The bentgrass mix had a much higher seed count due to the species having much smaller seed and a higher rate of seeding. Additionally, *Danthonia spicata* (L.) P. Beauv. ex Roem. & Schult., accounted for twice as much of the total bentgrass mix as the fescue mix. *D. spicata* has been noted to benefit from scarification and cold-stratification for ample germination (Navarete-Tindall and Van Sambeek, 2010). In this experiment, *D.*

spicata received no scarification and only had cold stratification in the fall sowing. *D. spicata* was present in much higher rates in the bentgrass mix; the poor germination rates of the bentgrass mix are likely in part to the poor germination of this species.

The mixes showed no differences in species richness or diversity. The only differences between these two mixes exist between their germination rates. It is reasonable to then conclude the differences are functionally negligible due to both mixes successfully establishing plots that were comparatively rich and diverse.

The rate of seeding was an important factor for germination rates, the total percentage of forb coverage, and the percentage of empty space within each plot. The 0.5x rate of seed provided the highest percentage of germinated seedlings, while the 2x rate resulted in the highest levels of forb coverage and lowest levels of empty space. Plots that had greater levels of germination should have had greater coverage, but this was not the case. The reason for this may be due to resource competition and available sunlight (Sauer and Struik, 1964; Jutila and Grace, 2002). Plots at higher seeding rates should have a greater likelihood of seeds germinating due to there being more seeds in each plot, but as seedlings established and began to cover a greater area in the more densely seeded plots, sunlight and moisture were scarcer. The scarcity of these conditions allows for the 0.5x rate to have a greater total percentage of germination, while still having less total coverage of forbs and more open space within the plot. The seeding rate did not have a significant effect in the fall sown plots, which had greater levels of grass coverage, which is to be expected as over-seeding of cool-season grass stands in the fall is a standard method of turf rehabilitation (Ricigliano, 2016).

The mix, rate, and season all had interactions that furthered the individual influence of these variables on the total percent germination within each plot. As previously stated, the season of sowing had the greatest effect. The interaction of these variables is consistent with the effects of the mix type, rate, and season of sowing.

Forb diversity was the major driver of overall species richness. Sowing in the spring favors forbs and thus also led to a greater level of species richness. It is difficult to claim whether a spring or fall sowing is better, as both successfully resulted in functional meadow plots, however, the composition of these plots differed greatly. Other mixes will likely have differing results depending on the comparative rates and number of species of forbs and cool-season grasses. In this experiment spontaneous vegetation pressure, which primarily consisted of undesirable native species and introduced weeds, was significantly higher in the fall. Sowing time is likely going to be determined by the overall goals of the meadow, and the timeline for installation provided. The data herein regarding sowing time and composition should be used to adjust the rates of grasses and forbs within a mix to account for sowing times to reach the desired composition, richness, or appearance of the meadow. Additionally, the differences in sowing time can help adjust the cost of a meadow mix, as forb seed is generally more expensive and forb rates could be reduced slightly when sown at a time of year that favors forb establishment.

With no differences observed in species richness or Simpson's Diversity Index between the mixes, cool-season grasses, both bunchgrasses and stoloniferous and rhizomatous grasses, can successfully form the base of a successful meadow mix. Further observations will need to be conducted to determine whether the more stoloniferous and rhizomatous grasses within the fescue mix are suitable for meadow mixes in the long term. After two years of observation, however, the differences are not significant.

Though the 0.5x rate led to the highest level of germination it did not lead to greater levels of species richness. The highest level of forb coverage was found at the 2x rate while the highest levels of species richness were found at the 2x and 1x rates. Both the first year and second years of the spring sown plots, and the first year between the fall and spring sowing had the same results: the 2x and 1x rates were not significantly different in creating a more species rich community. Due to the 0.5x rate yielding a less species rich plot, and that coverage being significantly less than both the 2x rate, the benefits of the increased levels of germination are negligible when applied to overall functionality of the meadow plot established.

Conclusion

Cool-season grasses can support functional meadows within the short term. As these meadow plots mature, further evaluations need to be conducted to determine how levels of diversity and richness change in the treatments over time. A 2x sowing rate does have benefits over the 1x rate, namely the low levels of open space after 12 weeks in the 2x plots. These benefits, however, may not justify doubling the cost of seed. The types of cool-season grasses used within a meadow mix also have not proven to adversely affect meadow establishment in the short-term. The season of sowing will have a large effect on the germination of certain types of seeds within the overall mix, as well as weed pressure, but both are viable. Forb seed is often expensive. A spring sowing is likely to be more economical due to the cheaper cost of cool-season grass seed and the proven success of overseeding cool-season grasses.

Chapter 3

EVALUATING FLOWER VISITATION IN A CONSTRUCTED COOL-SEASON GRASS MEADOW

Research Question and Hypothesis

Cool-season grasses are not the dominant grass type among meadows in the Mid-Atlantic region. The grasses that occupy designed and naturally occurring meadows are most often warm-season grasses (Dickerson et al., 1997; Latham, 2008). Little is understood about how larger landscape changes impact flower visitation (Ferreira et al., 2013). We expect to observe that cool-season grasses as the predominant grass type within our meadow mixes will not change the flower visitor dynamics previously reported in the literature for grassland and meadow habitats.

Materials and Methods

Flower visitation data included a count of flower visitors at the insect morphospecies level, as well as what flowers were visited by which morphospecies group. Morphospecies have been found to be an effective way of assessing species diversity for those who are not experts in insect identification (Barratt et al., 2003; Derraik, 2010). Fourteen morphospecies groups were developed from the orders of insects likely to be flower visitors. Further distinctions were then made to capture a large group of insect types while keeping the morphospecies groups easily recognizable so that they could be classified solely from visual observations in the field. Diptera were classified as hoverflies and other flies. Hymenoptera were classified as bees, wasps, and ants. Bees and wasps were then separated further into morphospecies groups of honey bees, bumblebees, sweat bees, and parasitic and non-parasitic wasps. Lepidoptera were divided into the morphospecies groups of butterflies, moths, and skippers. Coleoptera were not classified further than the level of order. Though not insects, arachnids were also included as a type of flower visitor due to the use of flowers by certain arachnids as ambush sites (Welti et al., 2016).

All observations of flower visitation were conducted visually using the spring-sown plots described in the previous chapter. Data collection consisted of three 5-minute observation periods for each plot occurring in the morning (between 8:00 and 10:00), the afternoon (between 13:00 and 15:00), and the evening (between 17:00 and 19:00) to ensure that a wide variety of visitor types could accurately be represented. Plots chosen for observation were selected randomly weekly from the spring sown plots. Each mix type and seeding rate were observed twice at each of the observation periods within a 24-hour window. Visitor observations began on May 27 and concluded on September 27, yielding observations that spanned 18 weeks and amounted to 108 observation hours.

Visitation was defined as any of the target morphospecies visiting any flower for any resource and contacting with any reproductive (Theodorou et al., 2016) or reward structures of the flower in the process while the flower was open to any degree (Yamaji and Ohsawa, 2016). The definition used here excludes extrafloral rewards but does not exclude nectar robbing as floral resources are still being contacted. Instances where this definition failed to capture the relationships between morphospecies and the visited plants or highlighted certain behaviors will be explained in the discussion section of this chapter.

During observations, the type of flower visitor according to the selected fourteen morphospecies, the plant visited, and the number of visits that occurred within the 5-minute observation window were recorded. The average sunlight conditions, temperature, and wind speed was recorded for the morning, afternoon, and evening, one hour after the start of observations. Data was collected from the Delaware Environmental Observing System at the University of Delaware Newark Ag Farm weather station, located approximately 425 m from the meadow plots. Sunlight conditions were judged qualitatively based on the average cloud cover during the observation session. See Table 5 for sunlight definitions and conditions. Flower visitor observation was conducted only when weather was favorable to flower visitors. The number of forbs in flower in each plot, as well as a general rating of the inflorescence display of each flowering forb species within the plot, were recorded to help explain possible differences in visitation rates. Inflorescence ratings utilized a scale of 1-3 with 1 being very few flowers available and 3 being at or near full bloom.

Table 5 Table explaining the conditions used for qualitative assessment of weather during flower visitor observations.

Weather condition	**Definition**
Sunny	No interferences from clouds during the entire observation session
Partly Cloudy	Interference by clouds for less than 50% of the observation session
Mostly Cloudy	Interference by clouds for over 50% of the observation session
Overcast	Cloud cover for the entire observation session

Rates of visitation were calculated to be the mean visits within the 5-minute observation window by visitor morphospecies to the plants they visited and were analyzed using two multi-factor analysis of variance (ANOVA) models and a student's t-test in JMP Version 14 (SAS Institute, Inc., Cary, NC, 1989-2020) at $\alpha=0.05$. The first ANOVA model examined the qualities of the mix type used in the plot, the rate of seed, and the environmental variables of weather, temperature, and wind speed. Interactions examined included the mix*rate, and all combinations of the three environmental variables. The second ANOVA model examined the time of day the observation occurred, the week during which the observation occurred, the inflorescence rating, the number of forbs in flower, and the plant species visited. Interactions between all factors, except plant species, in the second model were examined. Interactions between certain plants and visitor types were examined individually to look for trends and relationships between plants species and the visiting morphospecies groups. The sum of visits for each mix and seeding rate at each month of the observation period (excluding May) was calculated and Simpson's Index of Diversity was calculated for the morphospecies of visitors and the diversity of visits to flowering species for each mix and seeding rate.

Results

The rate of visitation was affected by the type of plot ($p=0.0026$), the sunlight conditions during the observation period ($p=0.0310$), and the wind speed during the observation period ($p=0.0001$). Significant interactions existed between sunlight*wind speed ($p=0.0207$) and between temperature*sunlight*wind speed ($p=0.0145$). Plots sown with the fescue mix received a slightly higher rate of visitors (3.14 visitors per observation period) compared to the bentgrass mix (2.87 visitors per observation period). Sunny conditions resulted in rates of visitation that were greater and significantly different than mostly cloudy conditions. Overcast and partly cloudy conditions were not found to be significantly different from either sunny or mostly cloudy conditions. Increased wind speed had a negative effect on the rate of visitations.

Visitor rates were strongly influenced by the time of the day during which observations took place ($p<0.0001$). Morning observation periods resulted in the greatest rate of visitation (3.47 mean visits per observation period) and were significantly different than the afternoon and evening observation periods. The afternoon and evening periods were not significantly different from each other and had mean rates of visitation of 2.79 and 2.73, respectively. Not all plant species experienced increased visitation during the morning observations. Some species had more visitation during the afternoon or evening.

Unsurprisingly, inflorescence ratings were significant ($p<0.0001$). Higher ratings indicated inflorescences with more open flowers than lower ratings, and the rate of visitation was higher in inflorescences with more available flowers to visit. The week during which observations took place was also highly significant ($p<0.0001$), which is to be expected given that observations began once two species were in flower across any of the two plots and ended when most species had ceased flowering. The week of observation had a negative effect on the rate of visitation, with visitation beginning to decline after 6 weeks of observations, or the 28^{th} week of the year. The decline in visitation coincided with the plant species that received the greatest abundance of visitors declining from its peak inflorescence rating. Interaction was observed between the week of observation, the time the observation occurred, and the number of forb species in flower ($p=0.0081$). Rates of visitation were also affected by the plant species within the plot ($p<0.0001$)

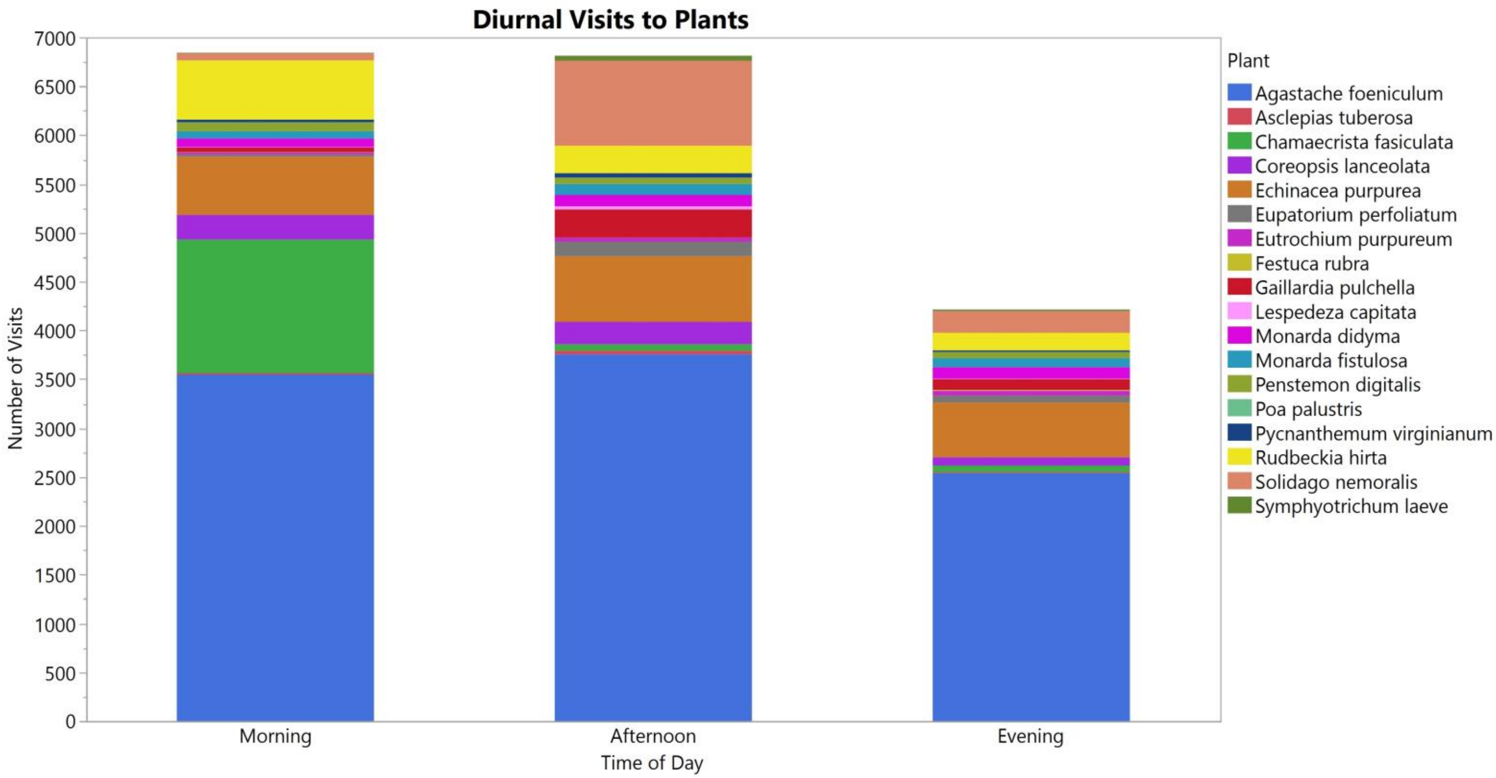


Figure 6 Total visitation to plant species at the three times of observation.

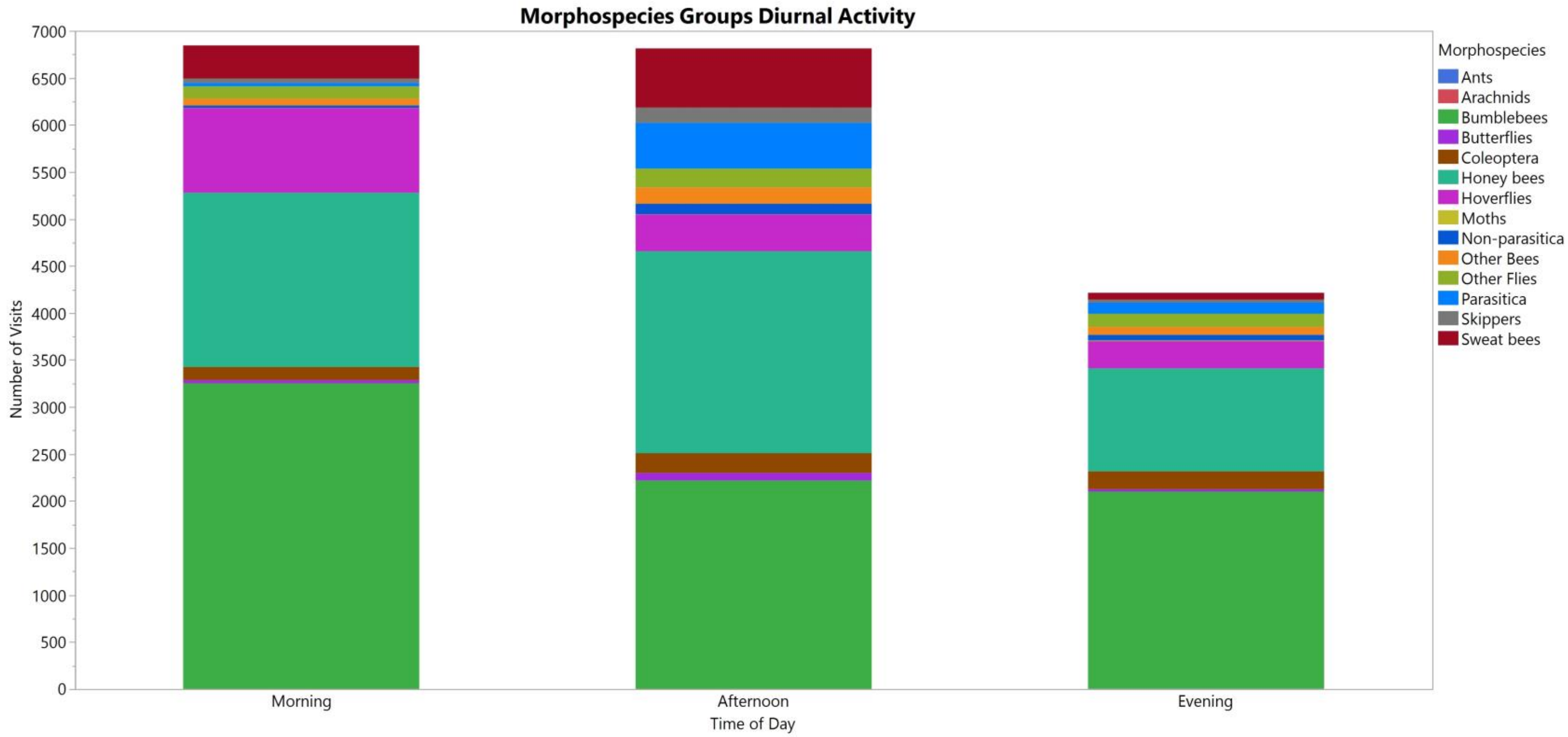


Figure 7 Total visitation by morphospecies group at the three times of observation.

Simpson's Index of Diversity revealed no significant differences in the diversity of visitor morphospecies between the type of mix, seeding rate, or the combination of mix type and seeding rate. The same was true of the diversity of visits that plants received: there were no significant differences in the diversity of visits that forbs received between the mix types, seeding rates, or the combination of mix type and seeding rate. When the diversity of visits that plants received was included in the model, it was found to be a significant indicator of visiting insect diversity (p=0.0068). As the diversity of plants increased, so too did the diversity of visitor types. A regression model of the diversity of morphospecies and the diversity of plants visited yielded an R^2 value of 0.34.

Agastache foeniculum (Pursh) Kuntze was the most frequently visited forb, far surpassing all the other forbs within the plots. *A. foeniculum* received 9,843 visits, or 55% of the total recorded visits. Four other forb species received over 1000 visits: *Echinacea purpurea* (L.) Moench. (1,828 visits), *Chamaecrista fasciculata* (Michx.) Greene (1,503 visits), *Solidago nemoralis* Aiton (1,166 visits), and *Rudbeckia hirta* L. (1,067 visits). Bumblebees were the most frequent morphospecies recorded, accounting for 7,562, or 42% of total visits. The next four most frequent morphospecies were honey bees (5,096 visits), hoverflies (1,584 visits), sweat bees (1,051 visits), and parasitic wasps (641 visits). While this research focused on the visitation of forbs within a meadow, it is worth noting that two cool-season grass species saw visitation from hoverflies where pollen was collected.

Table 6 Frequent visitors of all plants present and receiving visits within the spring sown plots. Visiting morphospecies listed were greater than or equal to 20% of the total visits for that plant species.

Plant	**Total Visits**	**Frequent Visiting Morphospecies**
Agastache foeniculum	9,843	Honey bees, Bumblebees
Asclepias tuberosa	63	Honey bees
Chamaecrista fasciculata	1,503	Bumblebees
Coreopsis lanceolata	566	Hoverflies
Echinacea purpurea	1,828	Bumblebees
Eupatorium perfoliatum	244	Other flies, Parasitic Wasps
Eutrochium purpureum	109	Bumblebees
Festuca rubra ssp. *rubra*	14	Hoverflies
Gaillardia pulchella	446	Bumblebees, Honey bees
Lespedeza capitata	40	Bumblebees, Other bees
Monarda didyma	323	Bumblebees
Monarda fistulosa	279	Bumblebees
Penstemon digitalis	218	Bumblebees, Other bees
Poa palustris	2	Hoverflies
Pycnanthemum virginianum	90	Honey bees
Rudbeckia hirta	1,067	Hoverflies, Sweat bees
Solidago nemoralis	1,166	Parasitic wasps
Symphyotrichum laeve	72	Honey bees

Discussion

The increased rate of visitation that the fescue plots received can likely be attributed to the extent to which *Agastache foeniculum* was present in those plots. An ANOVA found the mean coverage of *A. foeniculum* to be significantly higher in the fescue plots than the bentgrass plots (p=0.0005). Examining Simpson's Index of Diversity for the second year of the spring sown plots used for flower visitor observations, revealed no difference in diversity between the fescue and bentgrass plots (p=.7449), showing that the greater coverage of *A. foeniculum* in the fescue plots is not at the cost of plant species diversity. Therefore, the differences observed in the rates of visitation may be explained by the increased presence of *A. foeniculum* in the fescue plots which occurred by chance, as these plots were not any less diverse than the bentgrass plots.

Interaction was observed between the three environmental variables of sunlight, temperature, and wind speed. The role of the various environmental factors of temperature, wind speed, and sunlight are consistent with the existing literature (Kevan and Baker, 1983); visitation was more frequent on sunnier days, visitation increased with temperature, and higher wind speeds led to less visitation. Given the location of nearby structures, such as the Fischer Greenhouse Complex and the nearby parking lot, certain factors were likely mediated or accentuated through the presence of different microclimates throughout the meadow plots. Due to the nature of this study, examining a community of numerous species of plants and flower visitor morphospecies to discern their preferences and trends throughout the season, the day to day differences in visitation caused by environmental data is largely insignificant. What is of value is that in this novel cool-season grass meadow, environmental factors are having the same influence they have traditionally.

Higher rates of visitation in the morning observation periods are also consistent with the existing literature (Kevan and Baker, 1983). Extreme cases of this were seen with visitations to *C. fasciculata* where visits occurred almost exclusively in the morning, yielding a highly significant difference to the rate of visitation during the morning observation period (p<.0001). Ninety one percent of the visits to *C. fasciculata* occurred in the morning. It is unknown why visitors most frequently visited *C. fasciculata* during the morning observation periods, as no other study involving flower visitors to *C. fasciculata* disclosed the time periods when visitation was observed. Pollen is the only floral reward offered by *C. fasciculata* (Frazee and Marquis, 1994; Campbell et al., 2018). Pollen dispersal in plants has been shown to vary temporally and be subject to environmental variables (Wilmer, 2011). Though it has not been measured for this species, the greatest availability of floral rewards likely coincides with the frequency of visitation for the visiting species. The flowers were nearly exclusively visited by bumblebees, with bumblebees accounting for 97% of all visits. Visits from both parasitic and non-parasitic wasps were observed in the evening, but these visits were to extra floral nectaries located at the base of the petiole in all leaves after the 3rd or 4th true leaf (Rutter and Rausher, 2004), and thus not within the scope of our data collection.

The time of day in which visitors were present is likely driven by nectar production in the specific plants and general flower visitor behavior. *S. nemoralis*, for instance, was much more likely to be visited in the afternoon (p<.0001). This species was also mostly visited by parasitic wasps, who were also most active during the afternoon (p<.0001). Not all visitors, however, were visiting nectar sources. Hoverflies, for instance, were mostly observed visiting anthers and consuming pollen. Hoverflies were primarily observed during the first four weeks, which also coincided with maximum flowering periods of *Coreopsis lanceolata* and *R. hirta*, two species with traits that hoverflies have been shown to favor (Woodcock et al., 2014). A reduction can be seen in the visitation of hoverflies coinciding with the reduction of available *R. hirta* and *C. lanceolata* flower resources from week 1 to 5 (Figures 8 and 9). Hoverflies were also observed visiting the flowers of the cool-season grasses *Festuca rubra* ssp. *rubra* L. and *Poa palustris* L. While not insect pollinated, or plants traditionally visited by insects, the cool-season grasses were able to provide a resource for this morphospecies that primarily appeared earlier in the season. Hoverflies did not visit any of the warm-season grass species when they were in flower.

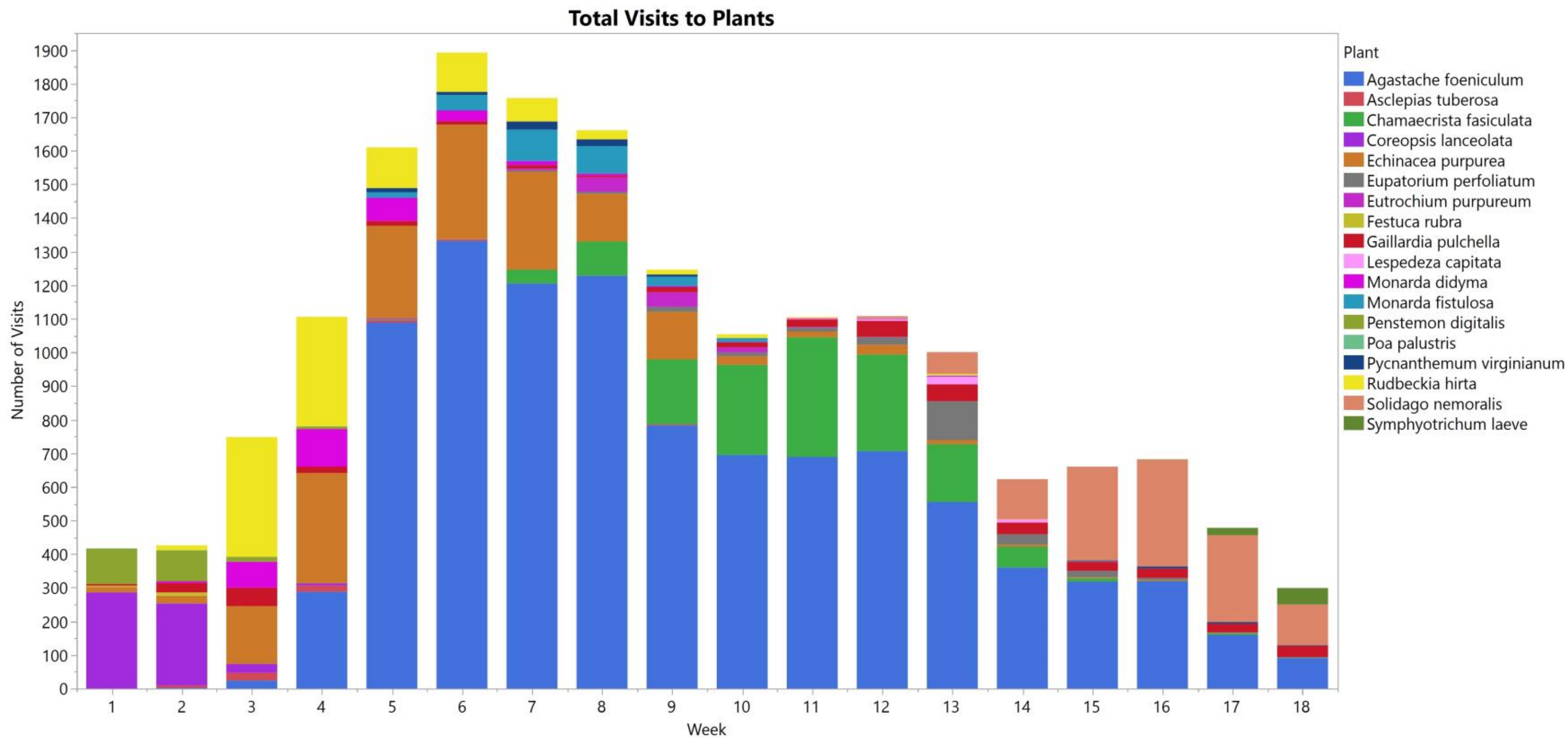


Figure 8 Total weekly visits to all plants that received visits in the spring sown plots.

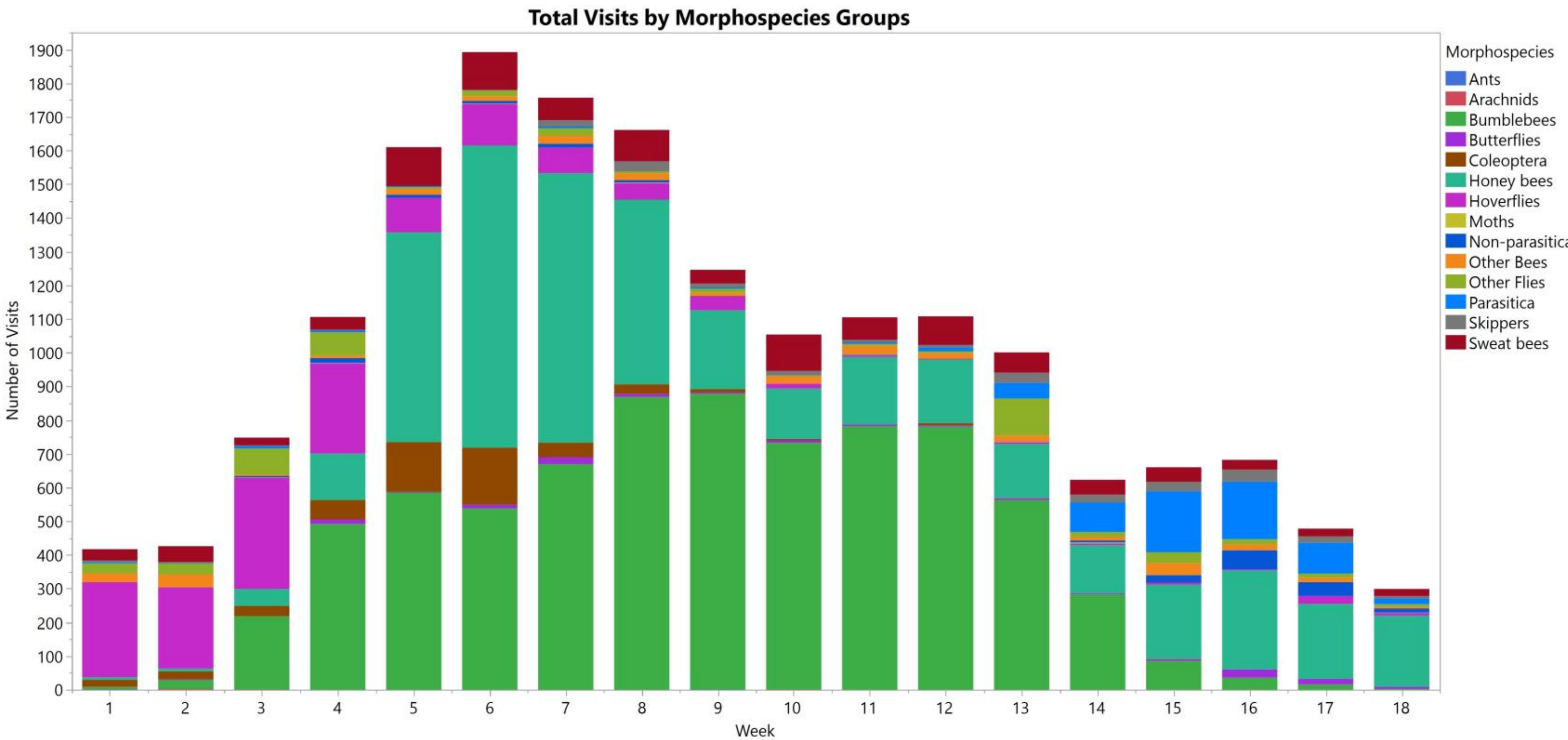


Figure 9 Total weekly visits by each morphospecies group in the spring sown plots.

The level of interaction between the week of observation, time of day the observation took place, and the number of forbs in flower was likely driven by the changes in the floral community from week to week. With *A. foeniculum* accounting for more visits than all other species combined, and the extremely high amount of morning visits to *C. fasciculata*, these two factors are likely influencing this interaction. Due to the flowering time of these two species closely following one another, and both occurring at a time where most forbs in these mixes have overlap in flowering, it is likely the number of forbs in flower is included in this interaction by chance, and is not really a significant part of this interaction. Indeed, the number of forbs in flower was highly insignificant when not part of this interaction group (p=0.9079). How many forbs are in flower should not be interpreted as significant; the drivers of visitation rates instead are individual plant species that are attracting visitors and that there is a steady availability of flowers to visit throughout the season. This conclusion is consistent with the existing literature of other grassland systems (Hegland, 2006).

The diversity of morphospecies was predicted by the diversity of plant species receiving visits. This has also been found in some studies of flower visitor interaction in grassland systems (Ebeling et al., 2008; Denning and Foster, 2018), but not all (Hegland, 2006). Additionally, some types of flower visitors seem to be more impacted by floral diversity than others (Denning and Foster, 2018). Remarkably little is known about how surrounding landscape changes impact flower visitor diversity (Ferreira et al., 2013). Our data suggests that plant species are the major drivers of flower visitation. The diversity of plants receiving visits was regressed to the diversity of flower visitor morphospecies providing visits yielding an R^2 value of 0.34. Despite the presence of numerous variables, many of which affect flower visitors and visitation and cannot be controlled, it is quite clear that a diversity of flowering plant material is a good indicator of a diverse flower visitor community. An examination of flower visitors at a finer taxonomic level and comparing monocultures of these plant species and the same species within a diverse meadow habitat might better reveal how individual plant species are driving flower visitor diversity, flower visitor richness, and broader landscape influences on flower visitors.

Conclusion

Many variables effect flower visitation in grassland/meadow communities, making it difficult to get a complete picture of the interactions taking place. Additionally, there are often numerous species that are attracting certain visitors at once, with considerable overlap in flower time during the times of peak visitation, further obfuscating which variables are truly influencing visitation. This research has shown that cool-season grass meadows are able to support flower visitors and display many of the same trends as other grassland habitats. Consistent with past research, the extent to which species are in flower and the diversity of plant species receiving visits are drivers of flower visitor diversity. Plant species receiving visits do not seem to need to be concurrently blooming to maximize visitation within the community. Instead, a consistent availability of flowers over the entire season seems to be the best assurance for creating and sustaining a flower visitor community.

Chapter 4

UTILIZING COOL SEASON GRASSES TO DEVELOP A MEADOW SOD

Research Objectives and Hypothesis

We believe that utilizing cool-season grasses in meadow seed mixes will open new opportunities for meadow establishment through meadow sod production. Cool-season grasses often have shallower root systems than many of the warm-season grasses encountered in grassland habitats (Brown et al., 2010). We believe these shallower root systems can hold a piece of sod with wildflower species together and allow for wildflower species to root past the competitive shallow root area once transplanted. This method is also likely to limit weed pressure due to the competitive root mass sod production facilitates (Caltrans, 2004). To test this hypothesis, meadow sod was grown first under greenhouse, and later field conditions. Sod was transplanted and differences in species richness were recorded.

Sod Development in a Greenhouse Setting

Materials and Methods

Greenhouse Sod Treatments and Sowing

Two mixes were developed from those used in the meadow sowing to test the viability of producing a meadow sod (Tables 7 and 8). These mixes were based on the mixes presented in Tables 2 and 3. Species that develop early deep root systems or are tuberous rooted were removed. These species were thought to be unlikely to survive transplant or would have produced a root system that could weaken the overall strength of the sod. Mixes were sown at three different seeding rates with five replications of each treatment. The rates of seeding were 1x, 0.5x and 2x the suggested seeding rate based on the same method of calculating seeding rates used by the NRCS (Houck, 2009). Tables 7 and 8 reflect the amount of seed used to sow all replications. The weight required per tray was calculated and the amount of seed needed was removed from the bulk mix for each replication. This changed process was necessitated since the amount of seed required for certain species in each individual treatment was too small to be effectively measured.

Table 7 Bentgrass dominant seed mix for greenhouse sod trial. Weight of seed shown per treatment is across all five replications. All weights reflect the amount of PLS needed.

Species	Common Name	kg PLS per ha	Rate	1x treatment (mg)	1/2x treatment (mg)	2x treatment (mg)
Deschampsia cespitosa	Tufted Hairgrass	2.2	15.00%	27.2	13.6	54.4
Danthonia spicata	Poverty Oatgrass	28.0	20.00%	453.6	226.8	907.2
Elymus trachycaulus	Slender Wheatgrass	6.7	5.00%	27.2	13.6	54.4
Poa palustris	Fowl Bluegrass	3.4	9.00%	24.5	12.3	49.0
Agrostis perennans	Upland Bentgrass	22.4	11.00%	199.6	99.8	399.2
Elymus virginicus	Virginia Wildrye	22.4	5.00%	90.7	45.4	181.4
Coreopsis lanceolata	Lanceleaf Coreopsis	7.8	1.00%	6.4	3.2	12.7
Echinacea purpurea	Purple Coneflower	13.5	3.00%	32.7	16.4	65.3
Gaillardia pulchella	Indian Blanket	13.5	4.00%	43.6	21.8	87.1
Monarda didyma	Scarlet Beebalm	4.0	1.00%	3.3	1.7	6.5
Monarda fistulosa	Wild Bergamot	4.0	1.00%	3.3	1.7	6.5
Penstemon digitalis	Foxglove Beardtongue	11.2	1.00%	9.1	4.6	18.1
Solidago nemoralis	Gray Goldenrod	11.2	1.00%	9.1	4.6	18.1
Pycnanthemum virginianum	Virginia Mountainmint	11.2	0.50%	4.6	2.3	9.1
Agastache foeniculum	Anise Hyssop	11.2	2.00%	18.2	9.1	36.3
Symphyotrichum laeve	Smooth Aster	11.2	3.00%	27.2	13.6	54.4
Tradescantia ohiensis	Ohio Spiderwort	11.2	3.00%	27.2	13.6	54.4
Viola sororia	Common Blue Violet	11.2	2.50%	22.7	11.4	45.4
Chamaecrista fasciculata	Partridge Pea	3.4	4.00%	10.9	5.5	21.8
Lespedeza capitata	Roundheaded Bush Clover	4.5	1.00%	3.7	1.9	7.3
Schizachyrium scoparium	Little Bluestem	11.2	2.50%	22.7	11.4	45.4
Sporobolus heterolepis	Prairie Dropseed	6.7	2.50%	13.6	6.8	27.2
Tridens flavus	Purpletop	28.0	2.00%	45.4	22.7	90.7

Table 8 Fescue dominant seed mix for greenhouse sod trial. Weight of seed shown per treatment is across all five replications. All weights reflect the amount of PLS needed.

Species	Common Name	kg PLS per ha	Rate	1x treatment (mg)	1/2x treatment (mg)	2x treatment (mg)
Deschampsia cespitosa	Tufted Hairgrass	2.2	10.00%	18.2	9.1	36.3
Festuca rubra spp. rubra	Creeping Red Fescue	13.5	30.00%	326.6	163.4	653.1
Danthonia spicata	Poverty Oatgrass	28.0	10.00%	226.8	113.4	453.6
Poa palustris	Fowl Bluegrass	3.4	10.00%	27.2	13.6	54.4
Elymus virginicus	Virginia Wildrye	22.4	5.00%	90.7	45.4	181.4
Coreopsis lanceolata	Lanceleaf Coreopsis	7.8	1.00%	6.4	3.2	12.7
Echinacea purpurea	Purple Coneflower	13.5	3.00%	32.7	16.4	65.3
Gaillardia pulchella	Indian Blanket	13.5	4.00%	43.6	21.8	87.1
Monarda didyma	Scarlet Beebalm	4.0	1.00%	3.3	1.7	6.5
Monarda fistulosa	Wild Bergamot	4.0	1.00%	3.3	1.7	6.5
Penstemon digitalis	Foxglove Beardtongue	11.2	1.00%	9.1	4.6	18.1
Solidago nemoralis	Gray Goldenrod	11.2	1.00%	9.1	4.6	18.1
Pycnanthemum virginianum	Virginia Mountainmint	11.2	0.50%	4.6	2.3	9.1
Agastache foeniculum	Anise Hyssop	11.2	2.00%	18.2	9.1	36.3
Symphyotrichum laeve	Smooth Aster	11.2	3.00%	27.2	13.6	54.4
Tradescantia ohiensis	Ohio Spiderwort	11.2	3.00%	27.2	13.6	54.4
Viola sororia	Common Blue Violet	11.2	2.50%	22.7	11.4	45.4
Chamaecrista fasciculata	Partridge Pea	3.4	4.00%	10.9	5.5	21.8
Lespedeza capitata	Roundheaded Bush Clover	4.5	1.00%	3.7	1.9	7.3
Schizachyrium scoparium	Little Bluestem	11.2	2.50%	22.7	11.4	45.4
Sporobolus heterolepis	Prairie Dropseed	6.7	2.50%	13.6	6.8	27.2
Tridens flavus	Purpletop	28.0	2.00%	45.4	22.7	90.7

A sandy loam, representative of soil used for agricultural crop production in the Sussex County Coastal Plain was dug from the top 8 cm in a former pasture at the University of Delaware's Carvel Agricultural Research and Education Center near Georgetown (Isaacs, personal communication). Prior to use, the sandy loam was autoclaved at a temperature of 120°C at 172 kPa for one hour. A 1020 tray (The HC Companies, Twinsburg, OH) containing 3 cm of the sandy loam, pitched at an approximate 2% slope, was used to mimic the conditions of field production for sod when grown over plastic. Holes were manually drilled at the low end of the tray to allow drainage. A dressing of 0.5 cm of Pro-mix BX potting soil (Premier Tech Horticulture, Rivière-du-Loup, Quebec, Canada) was applied on top of the sandy loam to ensure that seeds remained moist to foster better germination rates. Seeds were sown on March 28, 2018 in greenhouse conditions with daytime temperature set to 20°C, a night temperature of 18.3°C, and a morning temperature dip set to 16.7°C. The trays were arranged in a completely randomized design. Trays were randomized every three weeks to minimize edge effects. Humidity domes covered the trays for 10 days until adequate germination and establishment was observed.

Despite good germination, the seeding rate of *Festuca rubra ssp. rubra* L. appeared too low and was reseeded at three times the original rate. These trays were recovered to ensure adequate conditions for the newly added seed. The rate displayed in Table 8 reflects the final rate of *F. rubra* sown.

Sod Tray Evaluation

Sod trays that were bentgrass-dominant were evaluated and transplanted on May 15 (6 weeks after sowing), 2018. Fescue trays were evaluated and transplanted two weeks later, on May 30 (8 weeks after sowing), 2018. Species present within each tray were inventoried before transplant. Vegetation within each tray was then trimmed to a height of 15 cm. The sod within each tray was then held vertically for 10 seconds and subjected to a stretch test where the distance stretched by each piece of sod was measured. Two and three-factor analysis of variance (ANOVA) tests in JMP Version 14 (SAS Institute, Inc., Cary, NC, 1989-2020) at α=0.05 were conducted to discern statistical difference between the treatments regarding the species richness and distance stretched. Due to space constraints, each of the two mixes were transplanted in separate raised beds in a silt loam at an approximate depth of 3 cm. Each mix was transplanted in a completely randomized design. A second inventory of species richness occurred on September 6th to determine which species became dominant and how species richness changed from the time of transplant. An ANOVA was used again to determine if there were any differences between species richness at the time of transplant, and at the final species inventory.

Results

The stretch test revealed no differences in the distance stretched by each piece of sod regarding the mix type or seeding rate (Figure 5).

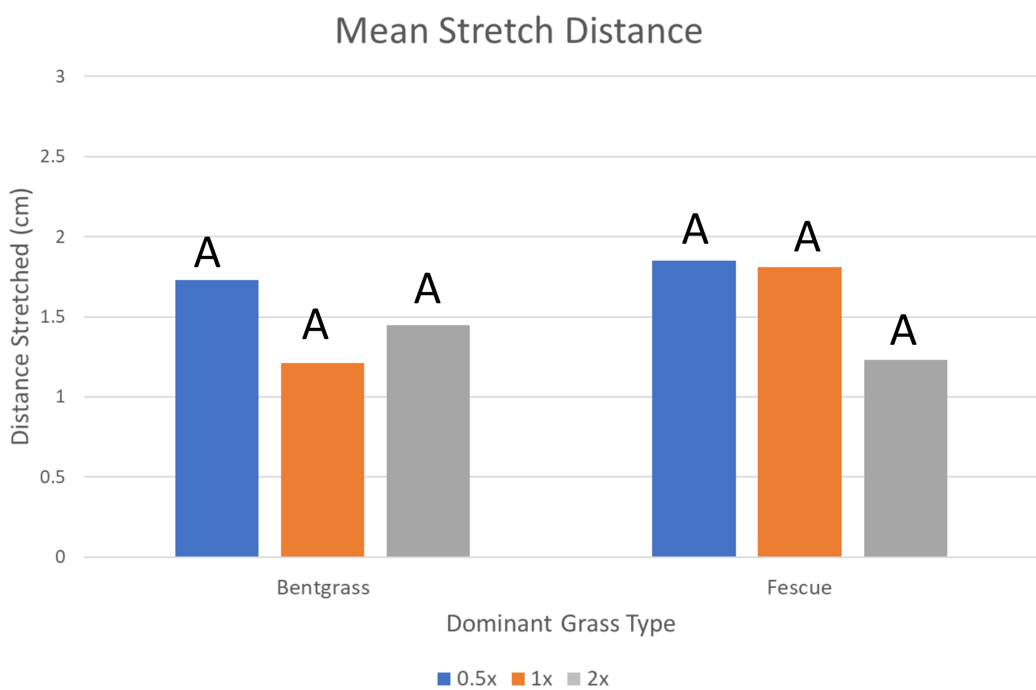


Figure 10 Mean distance stretched when sod was held vertically for 10 seconds. All treatments produced viable sod with no sod falling apart during the stretch test.

At the time of transplanting, species richness proportions varied between seeding rates (*p*=0.0016), but not between the mixes. Species richness increased as the seeding rate increased. This is to be expected under the favorable germination conditions of the greenhouse, with a greater amount of seed increasing the opportunity of each species to be represented by one seedling.

By the end of the observation period in September, the mix type was the only significant influence on species richness (*p*=0.0034). The bentgrass mix had a mean species richness proportion of 0.16 and the fescue mix had a mean species richness proportion of 0.25. When both richness proportions were included in a single model, the month was found to be significant with a *p*-value of *p*<0.0001, showing that a significant change in richness occurred between transplant and the final observations (Fig 6). Species richness declined for all treatments at all sowing rates by the end of the observation period (Fig. 7). Both the rate of seeding (p=0.0057) and the mix type (p=0.0459) contributed to the percent decline in species richness.

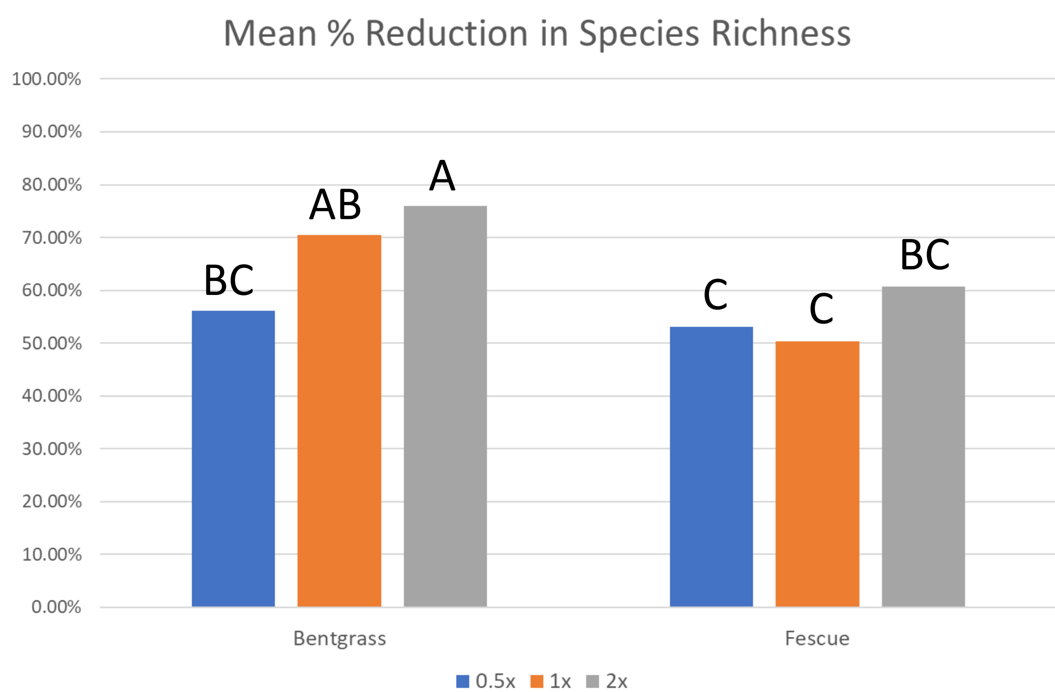
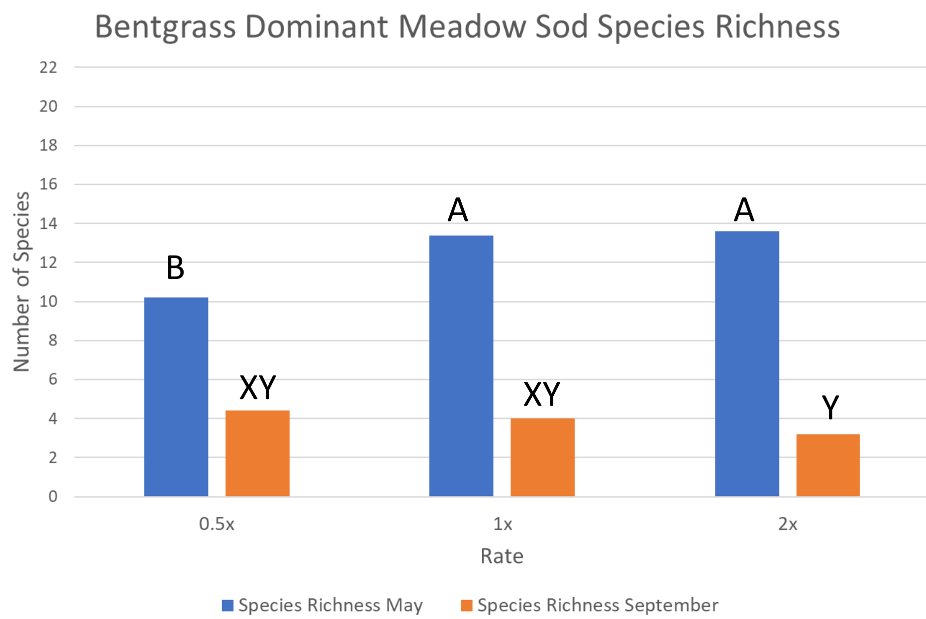


Figure 11 Total percent reduction in species diversity between time of transplant (May) and final observations (September).



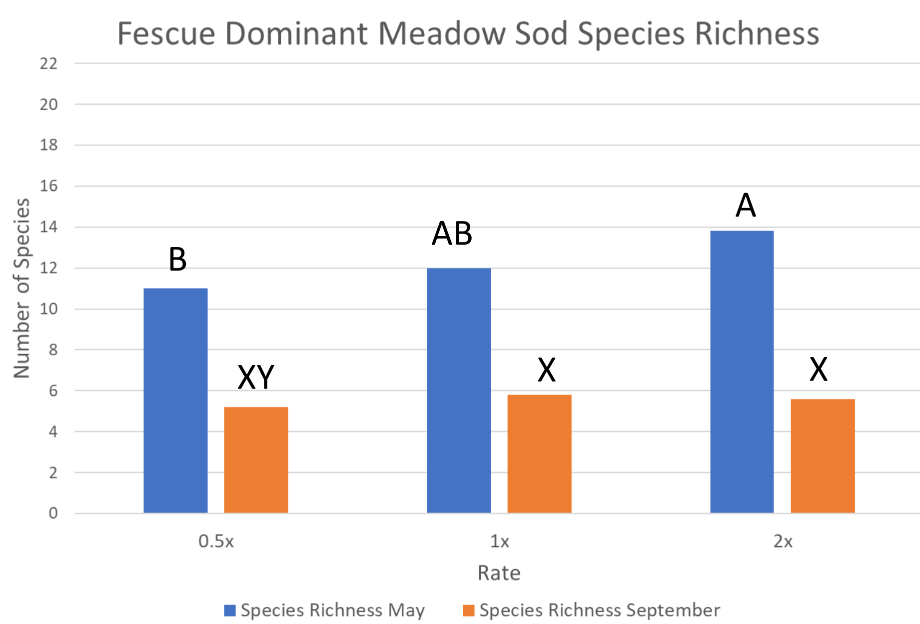


Figure 12 Decline in species richness within the bentgrass and fescue dominant mixes. Statistical levels apply to both graphs.

Discussion

Every tray resulted in a harvestable piece of sod with only minor differences in species richness. The mixes contained many species, and it was thought to be unlikely at the outset that all 22 or 23 species would be represented. Since this was the first attempt at creating meadow sod, part of our interest was to see what forb species would reliably germinate under controlled greenhouse conditions in order to refine and narrow our mix for future applications. This led to us increasing the rate of *Festuca rubra* ssp. *rubra*. Quickly germinating short-lived species, primarily *Gaillardia pulchella* Fougeroux and *Agastache foeniculum*, eventually out competed most species (Fig. 13). Our recommendation is that future mixes should be designed to have a smaller proportion *of G. pulchella* and *A. foeniculum* to promote greater success of other species, thus increasing long term species richness.

Figure 13 *Gaillardia pulchella* and *Agastache foeniculum* have completely dominated the transplanted sod.

Both mixes were sown at the same time in the greenhouse, but the bentgrass mix proved to be more competitive. The bentgrass mix began to show visual signs of stress due to the 3 cm rootzone sooner. A greater reduction in species richness from the time of transplant to the end of the assessment period was also observed. The transplant success of both mixes suffered from the dominance of *G. pulchella* and *A. foeniculum* outcompeting the slower growing forbs, and completely shading out all the grasses. Grasses tended to survive at the outside edges of the transplanted sod, as this was where the light was most abundant. Still, the 1x rate of the bentgrass dominant mix was not significantly different in its species richness than the 1x and 2x fescue treatments. Despite a large reduction in species richness, all sod proved to be transplantable and subsist with minimal inputs over a summer (Appendix B). The next step for meadow sod was to take it out of the greenhouse and attempt to produce it in field conditions at a larger scale.

Sod Development on Plastic

Materials and Methods

Seed Mixes

Based on the results of initial greenhouse trials, two new seed mixes were developed for sod production in the field over plastic (Tables 9 and 10). The new mixes reflect the findings of the initial greenhouse sod trial and changes were made to better accommodate longer lived forbs. Adventitious forbs proved to be too competitive in the initial greenhouse trial, so their percent inclusion in the sod mixes were reduced. Only one cool-season grass per mix was used to keep production costs low and to mimic a product that sod growers might be more likely to grow. The cool-season grasses were chosen due to their availability, cost of seed, and the perceived willingness of sod growers to grow these grasses (Jeff Everhart, Woodward Turf Farms, Remington VA, personal communication). This led to a *Festuca rubra ssp. rubra* dominant mix and a *Poa palustris* L. dominant mix. While *Agrostis perennans* was a dominant grass in the greenhouse trials, it was not selected for replication in the field trial due to perceived hesitancy of sod growers to produce it in the Mid-Atlantic (Jeff Everhart, Woodward Turf Farms, personal communication). Sod was grown on plastic to reduce weed competition, as well as for ease of harvest. Seeding rates were calculated using the same method recommended by the NRCS (Houck, 2009) explained in earlier chapters. Mixes were sown at 0.5x, 1x, and 2x of the suggested rate with four replications of each treatment in a completely randomized design.

Table 9 Fescue dominant seed mix for meadow sod production on plastic.

Species	Common Name	kg PLS per ha	Rate	1x PLS per plot (mg)	0.5x PLS per plot (mg)	2x PLS per plot (mg)
Festuca rubra	Creeping Red Fescue	13.5	60.00%	3240.0	1620.0	6480.0
Coreopsis lanceolata	Lanceleaf Coreopsis	7.8	3.50%	109.2	54.6	218.4
Echinacea purpurea	Purple Coneflower	13.5	6.00%	324.0	162.0	648.0
Gaillardia pulchella	Indian Blanket	13.5	2.50%	135.0	67.5	270.0
Monarda fistulosa	Wild Bergamot	4.0	3.50%	56.0	28.0	112.0
Penstemon digitalis	Foxglove Beardtongue	11.2	6.00%	268.8	134.4	537.6
Solidago nemoralis	Gray Goldenrod	11.2	4.00%	179.2	89.6	358.4
Rudbeckia hirta	Black-eyed Susan	0.5	2.50%	5.0	2.5	10.0
Pycnanthemum virginianum	Virginia Mountainmint	11.2	3.50%	156.8	78.4	313.6
Agastache foeniculum	Anise Hyssop	11.2	2.50%	112.0	56.0	224.0
Symphyotrichum laeve	Smooth Aster	11.2	5.00%	224.0	112.0	448.0

Table 10 Poa dominant seed mix for meadow sod production on plastic.

Species	Common Name	kg PLS per ha	Rate	1x PLS per plot (mg)	0.5x PLS per plot (mg)	2x PLS per plot (mg)
Poa palustris	Fowl Bluegrass	3.4	60.00%	816.0	408.0	1632.0
Coreopsis lanceolata	Lanceleaf Coreopsis	7.8	3.50%	109.2	54.6	218.4
Echinacea purpurea	Purple Coneflower	13.5	6.00%	324.0	162.0	648.0
Gaillardia pulchella	Indian Blanket	13.5	2.50%	135.0	67.5	270.0
Monarda fistulosa	Wild Bergamot	4.0	3.50%	56.0	28.0	112.0
Penstemon digitalis	Foxglove Beardtongue	11.2	6.00%	268.8	134.4	537.6
Solidago nemoralis	Gray Goldenrod	11.2	3.00%	134.4	67.2	268.8
Rudbeckia hirta	Black-eyed Susan	0.5	2.50%	5.0	2.5	10.0
Pycnanthemum virginianum	Virginia Mountainmint	11.2	3.50%	156.8	78.4	313.6
Agastache foeniculum	Anise Hyssop	11.2	2.50%	112.0	56.0	224.0
Symphyotrichum laeve	Smooth Aster	11.2	6.00%	268.8	134.4	537.6
Schizachyrium scoparium	Little Bluestem	11.2	1.00%	44.8	22.4	89.6

Soil and Establishment

The area was prepared with two applications of glyphosate (48.8% glyphosate, RoundUp WeatherMAX, Bayer AG, Leverkusen, Germany) at a rate of 5.8 L per hectare on August 24th and September 13th, 2018. The area was graded to an approximately 1% slope to accommodate drainage on top of the impermeable plastic.

A constructed sandy loam was used as a soil substrate overtop a 3.6 m x 304.8 m, 4 mil (0.1 mm) thick sheet of plastic. Soil was harvested from subsoil depth and screened in Waldorf, Maryland and donated by Luck Ecosystems (Luck Ecosystems, Richmond, VA). Initial rates of total organic content were found to be 2.2%. Ten percent Bloom (Bloom Soil, Washington, DC), a biosolid based soil conditioner, was added with the intent of increasing the rate of organic matter to a level of 3.6-4.6%. A separate soil test showed that increasing the organic content failed and the final rate of organic matter was 2.5%. The textural analysis of the soil was 57% sand, 31% silt, and 12% clay. Soil was applied at a 3 cm depth across the entirety of the plastic. Similar methods are used in the production of sports turf, primarily using bermudagrass (Penn State Center for Sports Surface Research, 2014).

Seed was broadcast by hand utilizing the same soil substrate as a carrier. Plots were 4 sq. meters (223.5 cm x 179 cm). Each plot was divided by a 35.5 cm wide buffer strip that was sown with *Festuca rubra* ssp. *rubra* at a rate of 13.6 kg per ha. These buffer strips also appeared at the first and last 35.5 cm of the plastic. The buffers were used to prevent erosion and runoff of seed from the plots during precipitation events. *Festuca rubra* ssp. *rubra* was used due to the amount of seed available and its quick germination time (when compared to many of the other seeds within the mixes). Plots were sown on October 10th, 2018. Upon sowing, plots were covered with an Agribon AG-19 row cover (Berry Global, Middletown, DE). Plots remained covered until high winds destroyed the row cover on February 25th, 2019.

Figure 14 Sod over plastic 3 months after sowing. The sod is between the red lines.

Transplant and Data Collection

The transplant site was prepared with a 2% solution of glyphosate (41% glyphosate, Ranger Pro, Monsanto, St. Louis, MO) and dethatched. Sod sown using the 0.5x rate failed to produce viable transplants, so only the 1x and 2x rates were transplanted. On June 3rd, sod that was deemed suitable for harvest was cut into 46 cm x 224 cm strips using a step-edger and transplanted on a silt loam. Strips of sod were moved by hand for transplant. Due to the weight of a single strip of sod, these strips were further cut into 3-4 pieces of sod for manageable transport to the transplant site several yards away. The total time between sowing and harvest was approximately 8 months. Supplemental water was provided for the first two weeks after transplant and was only provided once during drought conditions in August at the same rate (see Appendix B for complete water inputs).

Species richness (of species from the mixes) was measured at harvest and four months after transplant and was compared using two and three-factor ANOVA at $\alpha=0.05$ in JMP Version 14 (SAS Institute, Inc., Cary, NC, 1989-2020). Transplanted sod received one mowing to a height of 13 cm two weeks after transplant. Biomass of spontaneous vegetation (primarily weeds) was taken from 5 cm above the crown and dried in a drying oven at 49˚C for 6 days. Only vegetation within the treatments was sampled. Spontaneous vegetation that appeared between different treatments or between pieces of sod was not collected.

Results

The rate of seed had no effect on the biomass of spontaneous vegetation that occurred among the transplanted sod. The dominant grass species of the two mixes did affect the impact of spontaneous vegetation ($p=0.025$), seen in Figure 15. The species richness of spontaneous vegetation was not found to differ significantly between the seed mix, seeding rate, or the combination of these two variables. All treatments were just as likely to see the same number of species in the spontaneous vegetation.

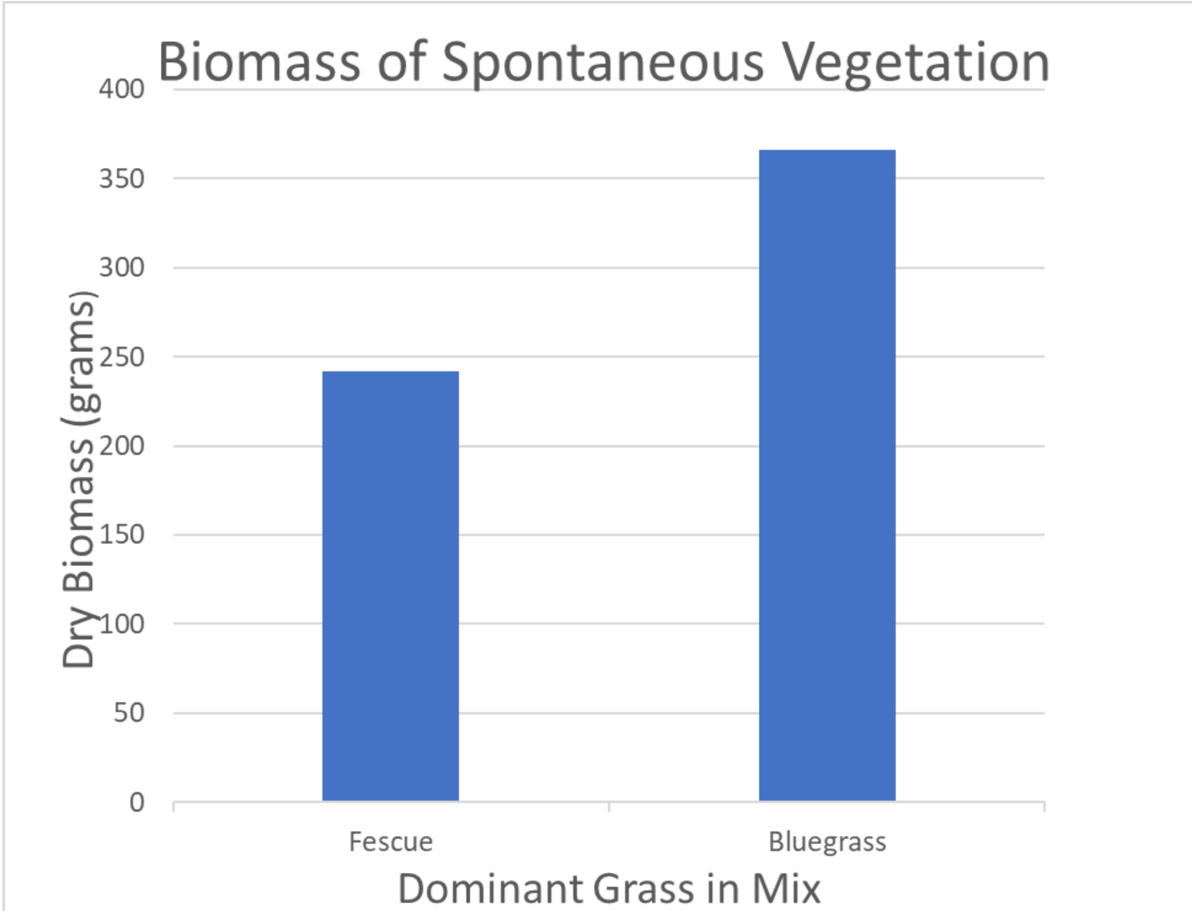


Figure 15 Difference in end of season biomass of spontaneous vegetation between the two mixes.

Differences in species richness at the time of harvest were not found to be significant (p=0.1256). Species richness was found to be significantly different between mixes at the end of the study (p=0.0306) with a mean richness of 2.18 for the fescue mix and 3.75 for the bluegrass mix. When species richness was examined under a single model, the mix (p=0.004) and the mix*rate interaction (p=0.0406) were found to be significant (Figure 16). The month was not found to be significant (p=0.3816), showing that there was not a significant decrease in species richness between transplant and our final observations. Utilizing more seed did not help establish a more species rich sod in all cases.

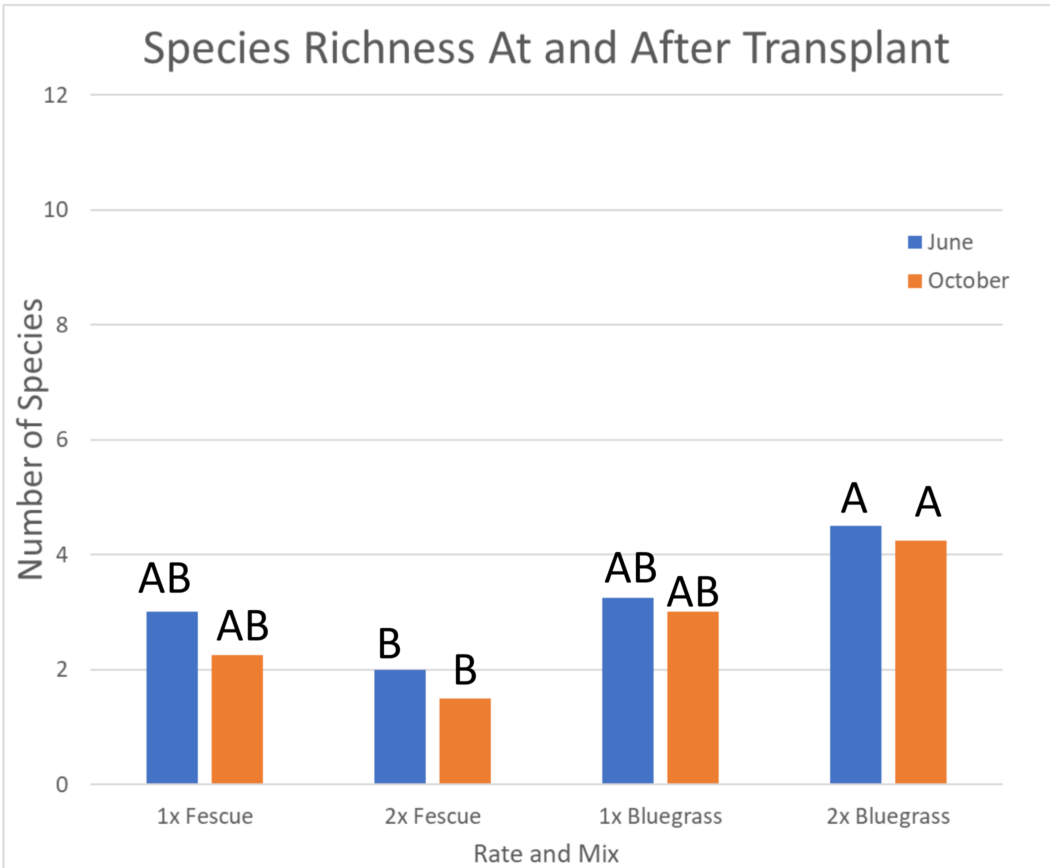


Figure 16 Species richness of transplanted sod at transplants (June) and at the end of season (October). Only species from the mixes were considered.

Discussion

The fall sowing time seemed to favor cool-season grass establishment while on the plastic. Though there were numerous forbs that germinated early on, the overall species richness was relatively low. We suspect that many of the early germinating forbs failed to survive the winter due to the constant freezing and thawing of the shallow soil base overtop the plastic. The experiment will be repeated with a spring sowing (mid-March) to see if forb establishment is more successful. A longer observation period is also worthwhile to test the durability of species richness.

Figure 17 Numerous forbs can be seen within the fescue mix. This photo was taken 3 months after sowing. Most of these forbs did not survive the winter.

The data suggests that the experiment would likely benefit from more repetitions all utilizing the 1x rate, as the 2x rate did not provide any reliable benefits compared to the 1x rate. Though the bluegrass dominant mix contained higher biomass levels of spontaneous vegetation, this may be due to the transplant shock it suffered, or due to how the fescue began to lay flat under its own weight, further obscuring the soil surface from the light that weed seeds would require to germinate (Figure 18).

Other methods of preparing the transplant site, such as preemergent weed control, could also be investigated to see how they may interact with newly transplanted wildflower sod. There are still a lot of unanswered questions and methods to be investigated before we can confidently establish wildflowers in sod for restoration or commercial use. However, we demonstrated enough success to indicate that sod remains a viable possibility for future wildflower meadow establishment.

Figure 18 Bluegrass (left of flag) and fescue (right of flag) sod two months after transplant. The bluegrass can be seen going dormant, while the fescue becomes matted. Several forb species can be seen in the bluegrass dominant sod. Weeds (primarily *Digitaria sp.*) can be seen gaining a foothold as well. Species pictured include *Solidago nemoralis* Aiton, *Monarda fistulosa* L., *Agastache foeniculum* (Pursh) Kuntze, *Symphyotrichum laeve* (L.) Á. Löve & D. Löve, and *Pycnanthemum virginianum* (L.) T. Dur. & B.D. Jacks. ex B.L. Rob. & Fernald.

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Appendix A

SPECIES FOUND WITHIN THESE SEED MIXES AND THE ATTRIBUTES THAT BROUGHT ON THEIR INCLUSION

Cool-Season Grasses

***Agrostis perennans* (Walter) Tuck. Upland bentgrass** – Unlike the popular bentgrasses used for golf course turf, *A. perennans* does not form stolons or rhizomes and instead forms dense tufts/clumps (Flora of North America Editorial Committee, floranorthamerica.org), making it a good candidate to support forbs among the patches it occurs in. *A. perennans* has been noted as shade-tolerant, making it a viable species to persist through the later part of the summer when forbs have taken over. As an autumn flowering grass, it also differed with *F. rubra* subsp. *rubra*, making its flowering time occur closer to the flowering time of most warm-season grasses. This species is common in all of the Mid-Atlantic states (Hitchock, 1950; USDA-NRCS, https://plants.sc.egov.usda.gov; Flora of North America Editorial Committee, floranorthamerica.org), occurring in highly variable environments, ranging from old fields to open woods and from sea level to higher elevations, but nearly always occurs in drier soils (Hitchcock, 1950). *A. perennans* can form tufts 20-80 cm tall, with flowering panicles 10-25 cm above that; however, plants did not appear to reach above 40 cm when in flower in our plots.

***Danthonia spicata* (L.) P. Beauv. Ex Roem & Schult. Poverty Oatgrass** – *D. spicata* formed the majority of the cool-season grasses (by anticipated % coverage, and by weight), but in actuality *A. perennans* occurred more frequently. *D. spicata* is found in all of the Mid-Atlantic states (Hitchock, 1950; USDA-NRCS, https://plants.sc.egov.usda.gov; Flora of North America Editorial Committee, floranorthamerica.org). The species is highly variable and often features cleistogamous flowers (Flora of North America Editorial Committee, floranorthamerica.org). The species has been evaluated for native turf use in golf courses (Navarrete-Tindall and Van Sambeek, 2010). *D. spicata* is one of the shorter grasses reaching a maximum height of about 25 cm, including the inflorescence (Flora of North America Editorial Committee, floranorthamerica.org).

***Deschampsia cespitosa* (L.) P. Beauv. Tufted hairgrass** – *D. cespitosa* is a shade tolerant cool-season grass that is slow to establish (St. John et al., 2011). The species is clump forming and found in all Mid-Atlantic states except Delaware (Flora of North America Editorial Committee, floranorthamerica.org), but it is present at Mt. Cuba Center (Korbonits, 2017). Vegetative growth is typically 10-35 cm tall, with flowers reaching another 8-40 cm above (Flora of North America Editorial Committee, floranorthamerica.org).

***Elymus trachycaulus* (Link) Gould Slender Wheatgrass** – *E. trachycaulus* was included only within the bentgrass dominant mix in order to emphasize cool-season grass diversity within the mix. *E. trachycaulus* is a variable grass, with some subgroups being slightly rhizomatous (Flora of North America Editorial Committee, floranorthamerica.org), but no rhizomes were encountered within our plots. The species can reach 175 cm when in flower and is found in all of the Mid-Atlantic states except Delaware (Flora of North America Editorial Committee, floranorthamerica.org). The species was chosen apart from other *Elymus* species for its distinct morphological differences from *Elymus virginicus*.

***Elymus virginicus* L. Virginia wildrye** – *E. virginicus* is a clump forming grass, widespread in all the Mid-Atlantic states (USDA-NRCS, https://plants.sc.egov.usda.gov; Flora of North America Editorial Committee, floranorthamerica.org). Reaching a height of 145 cm (Flora of North America Editorial Committee, floranorthamerica.org), it was functionally the tallest cool-season grass within the mixes, as *E. trachycaulus* was only present in the bentgrass mix and appeared far less frequently than *E. virginicus*. The species is common to both woodlands and wetter prairie/meadow areas (Shadow, 2009). This species was also the shortest and best establishing *Elymus* species native to the Mid-Atlantic trialed by Brader for meadow use (Brader, unpublished data).

***Festuca rubra* subsp. *rubra* L. Creeping red fescue** – *F. rubra* is a widely established, highly variable, cool-season grass (Flora of North America Editorial Committee, floranorthamerica.org). The subspecies *rubra* is found in all the Mid-Atlantic states (USDA-NRCS, https://plants.sc.egov.usda.gov) and is slightly rhizomatous (Flora of North America Editorial Committee, floranorthamerica.org). The species has been widely cultivated for reclamation, phytoremediation, and turf use (St. John et al., 2012). In our preliminary greenhouse sod trials, the recommended seeding rate of 4.5 kg per ha (St. John et al., 2012) was found to be insufficient and this rate was tripled to 13.5 kg per ha for all its subsequent uses in the seed mixes utilized in these experiments. *F. rubra* subsp. *rubra* was chosen due to widespread use and shade tolerance. The slightly rhizomatous habit of this grass was also a contributing factor to its selection in order to contrast the predominantly clump forming grasses in the bentgrass mix. Its sod forming habit has been noted to prevent invading vegetation (St. John et al., 2012), and this trait was selected to see if it would facilitate interspersed forb species as successfully as the bunchgrasses within the bentgrass mix.

***Poa palustris* L. Fowl bluegrass** – *P. palustris* is a stoloniferous grass that is variable to its environmental conditions, with grasses in sunnier meadow conditions being more loosely tufted (Flora of North America Editorial Committee, floranorthamerica.org). This species is found in all of the Mid-Atlantic states and is commonly utilized for soil stabilization and waterfowl feed (Flora of North America Editorial Committee, floranorthamerica.org). Given its stoloniferous habit, and the rhizomatous habit of *F. rubra* subsp. *rubra,* the fescue dominant mix contained 40% stoloniferous/rhizomatous mat forming grasses, making it considerably different from the bentgrass mix.

Forbs

***Agastache foeniculum* (Pursh) Kuntze (Lamiaceae) Anise hyssop** – *A. foeniculum* is native to the northern Mid-Atlantic states, excepting Virginia and Maryland (USDA-NRCS, https://plants.sc.egov.usda.gov). The species has been shown to have a generalist habit, attracting a variety of bee species, as well as Lepidopterans, and Syrphids (Garbuzov and Ratnieks, 2014). Other studies have shown this species to have visits over-represented by long-tongued bees (Robson et al., 2017). These differences are likely due to location, with Garbuzov and Ratnieks (2014) observing the plant in gardens in the UK, and Robson et al. (2017) observing visitations in established prairie communities.

***Asclepias tuberosa* L. (Apocynaceae) Butterfly milkweed** – *A. tuberosa* is native to all of the Mid-Atlantic states (USDA-NRCS, https://plants.sc.egov.usda.gov; Flora of North America Editorial Committee, floranorthamerica.org). The species has been recognized as a floral resource for fourteen Lepidoptera species (Tooker et al., 2002). *A. tuberosa* has also been noted to be visited by a variety of bees (Grundel et al., 2011), with *Bombus sp.* and *Apis sp.* and Lepidopterans proved to be the most effective visitors (Fishbein and Venable, 1996).

***Baptisia australis* (L.) R. Br. (Fabaceae) Blue wild indigo** – *B. australis* is native to all of the Mid-Atlantic states except Delaware (USDA-NRCS, https://plants.sc.egov.usda.gov) where it is not listed as present, however it is present at the University of Delaware Botanic Garden. This species was selected for being long-lived and its ability to fix nitrogen.

***Chamaecrista fasciculata* (Michx.) Greene (Fabaceae) Partridge Pea** – *C. fasciculata* is found in all of the Mid-Atlantic states (USDA-NRCS, https://plants.sc.egov.usda.gov). The flowers of *C. fasciculata* do not produce nectar, instead producing a large amount of pollen (Campbell et al., 2018). The species does have extrafloral nectaries (Campbell et al., 2018), but visitations to these nectaries were outside the scope of this experiment. Flowers of *C. fasciculata* are visited by several bee species and is pollinated primarily through “buzz” pollination (Thorp and Estes, 1975). The species has been recognized as a host to eleven species of Hymenopteran parasitoids (Tooker and Hanks, 2000) and eight species of Syrphid and Tachinid flies (Tooker et al., 2006), but it is unclear whether these visits were to flowers or extrafloral nectaries. This species was also chosen as one of the nitrogen fixing legumes within our mix.

***Coreopsis lanceolata* L. (Asteraceae) Lanceleaf coreopsis** – *C. lanceolata* is native to all of the Mid-Atlantic states (USDA-NRCS, https://plants.sc.egov.usda.gov; Flora of North America Editorial Committee, floranorthamerica.org). The species has been noted to attract several sweat bee species (Grundel et al., 2011).

***Echinacea purpurea* (L.) Moench (Asteraceae) Purple coneflower –** *E. purpurea* is recognized as native to all of the Mid-Atlantic states except Delaware (USDA-NRCS, https://plants.sc.egov.usda.gov). Other sources place its native range outside of the Mid-Atlantic (Flora of North America Editorial Committee, floranorthamerica.org).

***Eupatorium perfoliatum* L. (Asteraceae) Common boneset** – *E. perfoliatum* is found in all of the Mid-Atlantic states (USDA-NRCS, https://plants.sc.egov.usda.gov; Flora of North America Editorial Committee, floranorthamerica.org). The species has been recorded as a host for thirteen species of Syrphid and Tachinid flies (Tooker et al., 2006), as well as eight species of Hymenopteran parasitoids (Tooker and Hanks, 2000) and six beetle species (Graham et al., 2012). The species has also been recognized as a food source for multiple Lepidoptera species (Kirk and Belt, 2008). The species has also been recognized as a nectar source for seven diurnal Lepidoptera species (Tooker et al., 2002).

***Eutrochium purpureum* (L.) E.E. Lamont (Asteraceae) Joe-Pye weed** – *E. purpureum* is found in all of the Mid-Atlantic States (USDA-NRCS, https://plants.sc.egov.usda.gov; Flora of North America Editorial Committee, floranorthamerica.org). This species was among the tallest included in our seed mixes (up to 200 cm) (Flora of North America Editorial Committee, floranorthamerica.org). It was included at a low rate to provide a diversity among floral heights, as flower visitors have been shown to select for flower height in shorter plant communities (Sletvold et al., 2013). Ten diurnal Lepidoptera species have been recorded as visitors of this species in central Illinois (Tooker et al., 2002).

***Gaillardia pulchella* Foug. (Asteraceae) Indian blanket** – *G. pulchella* is listed as being native to all of the Mid-Atlantic states except Maryland (USDA-NRCS, https://plants.sc.egov.usda.gov), though other sources dispute this to a lesser (MoBot Plant Finder) or greater degree (Flora of North America Editorial Committee, floranorthamerica.org). The species has been recognized as supporting generalist pollinators (Ritchie et al., 2016).

***Lespedeza capitata* Michx. (Fabaceae) Roundheaded bush clover** – *L. capitata* is native to all of the Mid-Atlantic states (USDA-NRCS, https://plants.sc.egov.usda.gov). This species was primarily included as a nitrogen fixing legume. The species has been noted to fix nitrogen with penetrating roots that will reach 5-8 ft. deep into the soil, and produce branching lateral roots as well (USDA-NRCS, 2011).

***Liatris spicata* (L.) Willd. (Asteraceae) Dense blazing star** – *L. spicata* is native to all of the Mid-Atlantic states (USDA-NRCS, https://plants.sc.egov.usda.gov, Flora of North America Editorial Committee, floranorthamerica.org). The species has been noted to take several years to establish and reach flowering maturity (Levin, 1973). *L. spicata* is also a floral resource for several species of bees (Grundel et al., 2011).

***Monarda didyma* L. (Lamiaceae) Scarlet beebalm** – *M. didyma* is native to all of the Mid-Atlantic states (USDA-NRCS, https://plants.sc.egov.usda.gov). As its common name suggest, the flowers are red, leading the species to primarily attract hummingbirds as it fits the hummingbird pollination syndrome (Whitten, 1981). These findings were affirmed in the Mid-Atlantic through a three-year trial of Monarda species and cultivars at Mt. Cuba Center (Coombs, 2016). Though hummingbird facilitated flower visitations were not part of this study, there was only one hummingbird sighting during the flower visitation observation periods, during which no visitations were observed. Despite the flowers being primarily red, most of those observed in this study were pink to magenta, but generally darker than *M. fistulosa* L.

Monarda fistulosa **L. (Lamiaceae) Wild bergamot** – *M. fistulosa* is native to all of the Mid-Atlantic states (USDA-NRCS, https://plants.sc.egov.usda.gov). The species was ranked first in a study of 41 prairie wildflowers in terms of providing supplemental forage to bees in canola (*Brassica napus* L.) producing regions (Robson, 2014). The species was also recognized as a floral host to twenty-three diurnal Lepidoptera species, ranking among the highest of the 244 species rich community from which data was collected (Tooker et al., 2002).

Penstemon digitalis **Nutt. ex Sims (Plantaginaceae) Foxglove beardtongue** – *P. digitalis* is native to all of the Mid-Atlantic states (USDA-NRCS, https://plants.sc.egov.usda.gov, Flora of North America Editorial Committee, floranorthamerica.org). The species is a noted attractor of many bee species that preferred the shorter gullets of this species when compared to other *Penstemon spp.* in tall grass prairies (Clinebell II and Bernhardt, 1998). This may differ in the Mid-Atlantic, however, as all of the observed flower visits of *P. digitalis* were on plants within Missouri, and the southeastern Central Lowlands and north-central Coastal Plain populations of this species have been recognized to have smaller corollas than in Northern populations (17-23 mm versus 23-30 mm) (Flora of North America Editorial Committee, floranorthamerica.org). In Missouri, the most frequent visitors were found to be bumblebees (Clinebell II and Bernhardt, 1998), but in Illinois small and medium-sized bees were found to be the most frequent visitors (Dieringer and Cabera, 2002).

Pycnanthemum virginianum **(L.) B.L. Rob. & Fernald (Lamiaceae) Virginia mountainmint** – *P. virginianum* is native to all of the Mid-Atlantic states (USDA-NRCS, https://plants.sc.egov.usda.gov). The species has been noted as a host for eight species of Syrphid and Tachinid flies (Tooker et al., 2006) and four species of Hymenopteran parasitoids (Tooker and Hanks, 2000).

Rudbeckia hirta **L. (Asteraceae) Black-eyed Susan** – *R. hirta* is native to all of the Mid-Atlantic states (USDA-NRCS, https://plants.sc.egov.usda.gov, Flora of North America Editorial Committee, floranorthamerica.org). This species is regularly used in DelDOT's roadside meadows and was identified as reliably flowering in the first season and self-seeding by Susan Barton (Barton, University of Delaware PLSC, personal communication). The species has been noted as a host for six species of beetles (Graham et al., 2012) and seventeen species of Syrphid and Tachinid flies (Tooker et al., 2006). Additionally, twelve diurnal Lepidopterans have been recorded as visiting the species as a nectar source (Tooker et al., 2002).

Solidago nemoralis **Aiton (Asteraceae) Gray goldenrod** – *S. nemoralis* is native to all of the Mid-Atlantic states (USDA-NRCS, https://plants.sc.egov.usda.gov), though some sources list it as absent from Virginia (, Flora of North America Editorial Committee, floranorthamerica.org). This species was selected among the many species of goldenrod found in the Mid-Atlantic due to it being among the shortest of its genus (MoBot Plant Finder). The genus has been noted to be a food source for several specialized *Andrena spp*. and at least one *Perdita sp*. within the Mid-Atlantic (Norden, 2008). The species has also been noted to attract syrphid and tachinid flies (Robson, 2010). Six diurnal Lepidopterans have also been recorded as visitors (Tooker et al., 2002). Numerous bee species have also been recorded as visitors (Grundel et al., 2011).

***Symphyotrichum laeve* (L.) Á. Löve & D. Löve (Asteraceae) Smooth aster** – *S. laeve* is a fall-blooming perennial wildflower (MoBot Plant Finder) native to all of the Mid-Atlantic states (USDA-NRCS, https://plants.sc.egov.usda.gov, Flora of North America Editorial Committee, floranorthamerica.org). This species is the latest flowering species within our mixes. The species was also ranked fourth in a study of 41 prairie wildflowers in terms of providing supplemental forage to bees in canola producing regions (Robson, 2014). A member of the Asteraceae, the family is a host to several species of native bees (Norden, 2008). The genus serves as the host for several *Andrena spp*. and at least one *Perdita sp*. within the Mid-Atlantic (Norden, 2008). The species was also recognized as one of the most generalist supporting plants in northern prairies (Robson et al., 2017).

***Tradescantia ohiensis* Raf. (Commelinaceae) Ohio spiderwort** – *T. ohiensis* is the most common species of its genus in the United States and is native to all of the Mid-Atlantic states (Flora of North America Editorial Committee, floranorthamerica.org). The species has also been noted to be of special value to native bees by the Xerces Society for Invertebrate Conservation (Ladybird Johnson Wildflower Center, www.wildflower.org).

***Viola sororia* Willd. (Violaceae) Common blue violet** – *V. sororia* is an extremely common plant, native throughout the Mid-Atlantic (USDA-NRCS, https://plants.sc.egov.usda.gov, Flora of North America Editorial Committee, floranorthamerica.org). The species is thought to be subject to a changing “pollinator climate” due to its prevalence of cleistogamous flowers and phenotypic plasticity

(Beattie, 1974). Traditionally, this species has primarily been visited by solitary bees (Beattie, 1974), and is a host plant of the native violet specialist *Andrena violae* Robertson (Norden, 2008). The species also acts as a host for the larvae of fritillary butterflies (*Speyeria spp.* and *Boloria spp*.) (Eckel, 2018).

Zizia aurea **(L.) W.D.J. Koch (Apiaceae) Golden alexanders** – *Z. aurea* is a forb in the Apiaceae family that is native to all of the Mid-Atlantic states (USDA-NRCS, https://plants.sc.egov.usda.gov). The species has been noted to attract insects from the Halictidae, Syrphidae, and Apidae families (Parrish and Bazzaz, 1979). The species typically occurs in moister woodlands, thickets, glades and prairies (MoBot Plant Finder). Brader noted it established well in an unpublished trial of several meadow species (Brader, unpublished data). This species has also been noted as a host plant for thirteen beetle species (Graham et al., 2012). Five diurnal Lepidopterans have been recorded as visitors of *Z. aurea* (Tooker et al., 2002).

Warm-Season Grasses

Schizachyrium scoparium **(Michx.) Nash Little bluestem** – *S. scoparium* was primarily included due to its frequent usage in prairie restorations (Tober and Jensen, 2013). With a height of 50-150 cm (Hitchcock, 1950), but most commonly sitting around 50-120 cm (Missouri Botanical Garden (MoBot) Plant Finder), *S. scoparium* fit our desired height range. This species also features an orange-bronze fall color (MoBot Plant Finder). The species is listed as being native to all of the Mid-Atlantic states (Hitchock, 1950; USDA-NRCS, https://plants.sc.egov.usda.gov; Flora of North America Editorial Committee, floranorthamerica.org) and tolerates a wide variety of soil conditions (MoBot Plant Finder).

***Sporobolus heterolepis* (A. Gray) A. Gray Prairie dropseed** – *S. heterolepis* can be found in all the Mid-Atlantic states except Delaware and New Jersey (USDA-NRCS, https://plants.sc.egov.usda.gov; Flora of North America Editorial Committee, floranorthamerica.org), but it is present in Delaware at the University of Delaware and at Mt. Cuba Center (Korbonits, 2017). The species is fairly compact at 30-70 cm (Hitchcock, 1950) with pinkish-brown flowers appearing on panicles above (MoBot Plant Finder). *S. heterolepis* is listed as rare in both Pennsylvania and Maryland, only occurring in serpentine barrens, but is used widely in residential landscapes, and roadside and grassland revegetation (University of Maryland Center for Environmental Science, 2015?).

***Tridens flavus* (L.) Hitchc. Purpletop** – *T. flavus* is found in all of the Mid-Atlantic states (USDA-NRCS, https://plants.sc.egov.usda.gov; Flora of North America Editorial Committee, floranorthamerica.org) and commonly colonizes the roadside in Pennsylvania and further south (USDA-NRCS, 2002a) which indicated that it was likely to reliably germinate.

Appendix B

WEATHER DATA AND SUPPLEMENTAL INPUTS

Month	Day	Year	Avg Temp	Max Temp	Min Temp	Avg Wind Speed	Rainfall	Supplemental Irrigation	Supplemental Irrigation (Sod)	Additional Notes
			(°C)	(°C)	(°C)	($m.s^{-1}$)	(mm)	(mm)	(mm)	
May	1	2018	16.3	26.0 (16:30)	3.0 (05:40)	1.7	0	0	0	
May	2	2018	21.7	30.7 (16:00)	9.0 (06:25)	1.9	0	0	0	
May	3	2018	24.1	31.6 (16:55)	14.5 (02:40)	2.6	0	0	0	
May	4	2018	24.9	30.9 (15:35)	18.6 (06:25)	2.5	0	0	0	
May	5	2018	19.4	23.6 (00:05)	15.1 (24:00)	1.7	0	0	0	
May	6	2018	16.2	20.0 (16:35)	13.7 (23:10)	1.9	0	0	0	
May	7	2018	17.4	23.9 (16:20)	11.9 (07:00)	1.6	0	0	0	
May	8	2018	17.1	24.3 (17:40)	9.5 (05:50)	1.5	0	0	0	

Month	Day	Year	Avg Temp	Max Temp	Min Temp	Avg Wind Speed	Rainfall	Supplemental Irrigation	Supplemental Irrigation (Sod)	Additional Notes
			(°C)	**(°C)**	**(°C)**	**($m.s^{-1}$)**	**(mm)**	**(mm)**	**(mm)**	
May	9	2018	17.4	25.3 (15:45)	9.0 (06:05)	1.2	0	50.8	0	Spring plots sown
May	10	2018	17.2	25.3 (15:55)	8.6 (05:40)	1.5	0	0	0	
May	11	2018	20	25.4 (17:10)	14.2 (05:10)	1.4	0	0	0	
May	12	2018	17.6	24.5 (15:25)	12.9 (06:15)	2.1	17.3	0	0	
May	13	2018	13.7	16.1 (00:05)	12.7 (23:20)	2.4	24.9	0	0	
May	14	2018	16.9	23.1 (17:40)	12.5 (06:20)	1.3	8.9	0	0	
May	15	2018	22.1	29.8 (17:10)	16.7 (02:20)	2.3	22.9	0	0	Agrostis sod transplanted
May	16	2018	19.2	21.4 (13:30)	16.4 (24:00)	1.9	7.6	0	0	
May	17	2018	17.5	20.0 (17:55)	15.0 (05:45)	1.5	24.1	0	0	
May	18	2018	16.3	19.2 (10:25)	10.6 (23:40)	4	2.8	0	0	
May	19	2018	13.9	20.6 (24:00)	10.1 (03:25)	2.5	20.8	0	0	
May	20	2018	23.5	28.4 (15:30)	19.9 (23:15)	2.4	0.3	0	0	

Month	**Day**	**Year**	**Avg Temp**	**Max Temp**	**Min Temp**	**Avg Wind Speed**	**Rainfall**	**Supplemental Irrigation**	**Supplemental Irrigation (Sod)**	**Additional Notes**
			(°C)	**(°C)**	**(°C)**	**($m.s^{-1}$)**	**(mm)**	**(mm)**	**(mm)**	
May	21	2018	20.5	26.5 (17:25)	15.7 (24:00)	1.4	0	0	0	
May	22	2018	17.1	19.9 (10:15)	14.8 (02:15)	1.1	21.6	0	0	
May	23	2018	21.7	25.9 (16:40)	17.4 (23:50)	1.6	0	0	0	
May	24	2018	22.1	28.1 (18:00)	15.8 (01:50)	1.3	0	0	0	
May	25	2018	22.5	28.8 (16:05)	13.4 (05:55)	2.3	0	0	0	
May	26	2018	25.6	31.3 (16:15)	18.9 (06:00)	1.7	0	0	0	
May	27	2018	21.3	26.0 (10:25)	15.1 (24:00)	2.6	4.6	0	0	
May	28	2018	17.1	20.9 (16:10)	14.0 (04:30)	1.7	0	0	0	
May	29	2018	21.6	27.5 (15:25)	17.9 (01:25)	1.1	0.3	0	0	
May	30	2018	20.9	25.4 (15:50)	17.6 (24:00)	2	0	0	0	Fescue sod transplanted
May	31	2018	20.9	25.6 (16:35)	17.3 (03:30)	1.9	2.8	0	0	
June	1	2018	24.1	28.2 (17:45)	21.4 (06:00)	0.9	0.8	0	0	

Month	Day	Year	Avg Temp (°C)	Max Temp (°C)	Min Temp (°C)	Avg Wind Speed ($m.s^{-1}$)	Rainfall (mm)	Supplemental Irrigation (mm)	Supplemental Irrigation (Sod) (mm)	Additional Notes
June	2	2018	24.2	29.4 (15:05)	20.7 (05:55)	1.2	11.7	0	0	
June	3	2018	16.6	22.2 (02:05)	11.8 (22:25)	4.1	13.7	0	0	
June	4	2018	16.9	22.5 (18:50)	11.5 (06:05)	1.6	1.3	0	0	
June	5	2018	19.1	25.9 (16:25)	11.7 (05:30)	2.1	2.3	0	0	
June	6	2018	18	21.8 (14:10)	14.0 (05:15)	1.3	0	0	0	
June	7	2018	19.1	23.4 (12:45)	14.7 (06:35)	1.4	0	0	0	
June	8	2018	20.8	26.8 (14:25)	13.4 (05:45)	1	0	0	0	
June	9	2018	22.7	28.7 (14:00)	18.0 (05:55)	1.1	0	0	0	
June	10	2018	19.8	24.2 (12:30)	15.1 (24:00)	2.6	7.4	0	0	
June	11	2018	16	19.8 (17:55)	12.7 (23:55)	2.2	20.3	0	0	
June	12	2018	17.3	23.0 (14:20)	9.6 (05:45)	1.7	0	0	0	
June	13	2018	22.4	26.3 (17:50)	18.4 (03:30)	2.1	0	0	0	

Month	**Day**	**Year**	**Avg Temp (°C)**	**Max Temp (°C)**	**Min Temp (°C)**	**Avg Wind Speed ($m.s^{-1}$)**	**Rainfall (mm)**	**Supplemental Irrigation (mm)**	**Supplemental Irrigation (Sod) (mm)**	**Additional Notes**
June	14	2018	24.9	28.8 (17:45)	20.8 (24:00)	2.3	0	0	0	
June	15	2018	21.7	26.8 (17:05)	16.0 (06:00)	1.5	0	0	0	
June	16	2018	22	28.2 (15:55)	13.7 (05:50)	1.2	0	0	0	
June	17	2018	24.6	31.3 (15:40)	16.2 (05:35)	1	0	0	0	
June	18	2018	26.4	32.4 (16:50)	19.1 (05:10)	2	0	0	0	
June	19	2018	27	30.5 (17:05)	22.1 (23:35)	1.7	0	0	0	
June	20	2018	24.4	30.2 (12:55)	17.8 (05:15)	1	0.5	0	0	
June	21	2018	23.7	28.2 (18:15)	21.4 (10:05)	1.3	0.8	0	0	
June	22	2018	20.5	22.2 (11:25)	16.6 (20:55)	2.6	2	0	0	
June	23	2018	20	23.3 (18:35)	17.8 (06:25)	1.9	4.6	0	0	
June	24	2018	25.4	30.7 (15:05)	21.3 (06:05)	1.9	0	0	0	
June	25	2018	23.2	27.9 (16:05)	18.8 (23:50)	1.7	0	0	0	

Month	Day	Year	Avg Temp	Max Temp	Min Temp	Avg Wind Speed	Rainfall	Supplemental Irrigation	Supplemental Irrigation (Sod)	Additional Notes
			(°C)	(°C)	(°C)	($m.s^{-1}$)	(mm)	(mm)	(mm)	
June	26	2018	21	26.6 (14:25)	14.0 (02:25)	2.1	0	0	0	
June	27	2018	21.2	23.7 (21:40)	16.9 (04:00)	1.4	0.3	0	0	
June	28	2018	26.5	30.8 (14:10)	22.7 (01:25)	2.2	0	0	0	
June	29	2018	27.3	32.6 (16:30)	21.6 (04:25)	1.2	0	0	0	
June	30	2018	27.9	34.4 (17:05)	19.6 (05:55)	1.1	0	0	0	
July	1	2018	28.8	35.2 (15:05)	21.6 (05:45)	1.3	0	0	0	
July	2	2018	28.8	35.5 (16:05)	21.4 (05:50)	1.1	0	25.4	25.4	Spring plots and greenhouse sod
July	3	2018	28.8	35.5 (15:45)	23.7 (05:40)	1.3	0	0	0	
July	4	2018	27.5	32.9 (15:20)	22.0 (05:55)	1.3	0	0	0	
July	5	2018	28	33.0 (14:25)	24.3 (05:40)	1.6	0	0	0	
July	6	2018	26.2	28.4 (10:40)	22.2 (24:00)	1.8	0.8	0	0	
July	7	2018	21.3	26.0 (16:20)	15.7 (24:00)	2.4	0	0	0	

Month	Day	Year	Avg Temp	Max Temp	Min Temp	Avg Wind Speed	Rainfall	Supplemental Irrigation	Supplemental Irrigation (Sod)	Additional Notes
			(°C)	(°C)	(°C)	(m.s^{-1})	(mm)	(mm)	(mm)	
July	8	2018	21.1	28.2 (17:10)	12.1 (05:50)	1.3	0	0	0	
July	9	2018	22.9	30.2 (16:40)	13.4 (05:50)	1.1	0	0	0	
July	10	2018	26.3	33.9 (17:00)	16.8 (06:05)	1.2	0	25.4	25.4	Spring plots and greenhouse sod
July	11	2018	27.1	31.6 (16:20)	23.4 (06:05)	1.6	0	0	0	
July	12	2018	24.2	29.3 (16:40)	18.4 (06:00)	1.4	0	0	0	
July	13	2018	23.8	30.2 (15:35)	17.8 (06:00)	1.2	0	10	10	Spring plots and greenhouse sod
July	14	2018	24.7	31.5 (16:30)	16.0 (05:40)	1.7	0	0	0	
July	15	2018	23.7	27.5 (17:45)	20.4 (03:50)	1	6.9	0	0	
July	16	2018	27.4	34.1 (16:25)	20.4 (05:45)	1.6	0	0	0	
July	17	2018	26	32.7 (13:05)	22.0 (16:35)	1.6	3	0	0	
July	18	2018	24.8	29.9 (15:05)	19.9 (24:00)	1.6	0	0	0	
July	19	2018	23.4	29.6 (16:25)	15.6 (05:45)	1.1	0	0	0	

Month	Day	Year	Avg Temp	Max Temp	Min Temp	Avg Wind Speed	Rainfall	Supplemental Irrigation	Supplemental Irrigation (Sod)	Additional Notes
			(°C)	**(°C)**	**(°C)**	**($m.s^{-1}$)**	**(mm)**	**(mm)**	**(mm)**	
July	20	2018	23	28.6 (15:25)	15.5 (05:40)	1.6	0	0	0	
July	21	2018	20.3	22.4 (11:55)	18.9 (05:10)	2.8	43.4	0	0	
July	22	2018	23.6	28.6 (15:40)	19.5 (06:05)	2.6	9.1	0	0	
July	23	2018	25.8	28.3 (14:50)	24.4 (24:00)	3.7	1.5	0	0	
July	24	2018	25.2	28.2 (11:50)	22.0 (05:30)	3.2	41.9	0	0	
July	25	2018	24	27.1 (13:20)	22.0 (23:50)	1.8	33.8	0	0	
July	26	2018	24.8	30.4 (17:00)	21.1 (06:00)	0.9	0	0	0	
July	27	2018	24.3	30.6 (14:15)	20.6 (04:35)	1	7.6	0	0	
July	28	2018	24.4	29.3 (15:40)	19.8 (04:45)	0.8	0	0	0	
July	29	2018	23.2	28.5 (16:20)	18.5 (06:15)	0.9	0	0	0	
July	30	2018	21.5	24.8 (12:10)	18.4 (03:00)	1	0	0	0	
July	31	2018	23.3	27.2 (16:55)	18.7 (00:05)	1.5	0	0	0	

Month	**Day**	**Year**	**Avg Temp**	**Max Temp**	**Min Temp**	**Avg Wind Speed**	**Rainfall**	**Supplemental Irrigation**	**Supplemental Irrigation (Sod)**	**Additional Notes**
			(°C)	**(°C)**	**(°C)**	**($m.s^{-1}$)**	**(mm)**	**(mm)**	**(mm)**	
August	1	2018	26.5	30.4 (16:40)	23.1 (06:15)	2.5	6.3	0	0	
August	2	2018	25.5	30.5 (15:50)	21.8 (03:05)	1.6	3	0	0	
August	3	2018	25	29.5 (14:55)	22.7 (20:20)	1.5	16	0	0	
August	4	2018	25.4	30.1 (17:25)	22.7 (23:15)	1.4	6.1	0	0	
August	5	2018	26.9	32.4 (14:30)	21.4 (06:00)	0.8	0	0	0	
August	6	2018	27.3	32.8 (15:00)	21.6 (06:55)	1.1	0	0	0	
August	7	2018	27	32.0 (16:05)	22.3 (05:20)	1.4	0	0	0	
August	8	2018	26.9	31.6 (15:30)	21.1 (06:20)	1.1	1.3	0	0	
August	9	2018	26	30.9 (16:55)	21.5 (06:20)	1.4	1	0	0	
August	10	2018	26.3	31.6 (15:15)	20.1 (06:35)	0.8	0	0	0	
August	11	2018	24.6	31.1 (15:00)	20.5 (24:00)	1.2	28.7	0	0	
August	12	2018	24.2	28.4 (13:35)	20.2 (06:15)	0.8	0	0	0	

Month	**Day**	**Year**	**Avg Temp**	**Max Temp**	**Min Temp**	**Avg Wind Speed**	**Rainfall**	**Supplemental Irrigation**	**Supplemental Irrigation (Sod)**	**Additional Notes**
			(°C)	**(°C)**	**(°C)**	**($m.s^{-1}$)**	**(mm)**	**(mm)**	**(mm)**	
August	13	2018	24.3	28.6 (14:30)	20.0 (23:25)	1.1	44.2	0	0	
August	14	2018	22.5	27.2 (14:10)	19.4 (03:55)	1.3	7.1	0	0	
August	15	2018	25.7	30.7 (17:05)	20.5 (05:50)	1.4	0	0	0	
August	16	2018	26	31.0 (15:45)	21.7 (05:05)	0.8	0	0	0	
August	17	2018	27.4	32.3 (14:45)	21.5 (06:15)	1.5	0	0	0	
August	18	2018	25.5	30.2 (16:15)	22.6 (06:00)	1.3	16	0	0	
August	19	2018	21.1	23.7 (00:05)	19.3 (24:00)	1.6	4.6	0	0	
August	20	2018	21.5	24.1 (18:00)	19.1 (05:25)	1.7	0	0	0	
August	21	2018	22.9	26.5 (13:25)	20.6 (03:45)	2	3.6	0	0	
August	22	2018	24.1	28.0 (15:45)	21.3 (06:50)	1.6	4.8	0	0	
August	23	2018	21.3	25.9 (17:50)	17.4 (24:00)	1.5	0	0	0	
August	24	2018	21.3	28.2 (15:30)	13.9 (06:40)	0.8	0	0	0	

Month	Day	Year	Avg Temp	Max Temp	Min Temp	Avg Wind Speed	Rainfall	Supplemental Irrigation	Supplemental Irrigation (Sod)	Additional Notes
			(°C)	(°C)	(°C)	($m.s^{-1}$)	(mm)	(mm)	(mm)	
August	25	2018	20.9	27.0 (16:05)	14.1 (06:30)	0.8	0	0	0	
August	26	2018	22.9	28.8 (15:40)	16.0 (06:25)	1.4	0	0	0	
August	27	2018	25.8	31.4 (15:35)	19.9 (05:10)	0.8	0	0	0	
August	28	2018	28.1	33.4 (15:15)	22.8 (03:00)	1.2	0	0	0	
August	29	2018	28.8	34.1 (15:05)	24.6 (01:25)	1.5	0	0	0	
August	30	2018	27.4	31.5 (16:30)	24.2 (06:25)	1.1	0	0	0	
August	31	2018	23.6	25.8 (13:50)	20.9 (23:45)	2.2	18	0	0	
September	1	2018	22.5	24.8 (13:30)	20.4 (04:35)	1.7	8.1	0	0	
September	2	2018	24.9	31.2 (16:40)	21.3 (06:05)	1.1	0	0	0	
September	3	2018	27.1	33.2 (14:30)	21.8 (06:10)	0.7	0	0	0	
September	4	2018	27.8	33.3 (15:05)	22.5 (06:35)	0.7	0	0	0	
September	5	2018	28	33.7 (14:30)	22.6 (06:40)	0.7	0	0	0	

Month	Day	Year	Avg Temp	Max Temp	Min Temp	Avg Wind Speed	Rainfall	Supplemental Irrigation	Supplemental Irrigation (Sod)	Additional Notes
			(°C)	(°C)	(°C)	($m.s^{-1}$)	(mm)	(mm)	(mm)	
September	6	2018	27.3	33.7 (15:15)	22.8 (06:35)	1.3	0	0	0	Greenhouse sod final data.
September	7	2018	25.1	29.2 (16:30)	22.1 (06:35)	1.1	1.5	0	0	
September	8	2018	19.3	22.4 (00:05)	16.2 (24:00)	2	26.2	0	0	
September	9	2018	15	16.3 (15:15)	13.8 (07:00)	3.2	65.8	0	0	
September	10	2018	17.8	21.9 (14:55)	13.7 (05:35)	2.8	8.6	0	0	
September	11	2018	20.4	23.2 (16:55)	18.0 (02:50)	1.1	2	0	0	
September	12	2018	23.8	28.7 (13:50)	21.3 (06:15)	0.9	6.6	0	0	
September	13	2018	23.7	25.9 (13:30)	22.0 (24:00)	2	0	0	0	
September	14	2018	22.2	24.5 (16:25)	20.6 (05:35)	2.4	0	0	0	
September	15	2018	22.4	27.0 (14:25)	18.9 (24:00)	1.4	0	0	0	
September	16	2018	21.8	28.6 (14:50)	16.9 (05:10)	1	0	0	0	
September	17	2018	22.7	25.8 (12:10)	18.4 (00:15)	1.6	2.3	0	0	

Month	Day	Year	Avg Temp	Max Temp	Min Temp	Avg Wind Speed	Rainfall	Supplemental Irrigation	Supplemental Irrigation (Sod)	Additional Notes
			(°C)	(°C)	(°C)	($m.s^{-1}$)	(mm)	(mm)	(mm)	
September	18	2018	24.3	27.7 (11:20)	20.4 (23:55)	1.6	3	0	0	
September	19	2018	23.2	28.4 (16:00)	18.7 (04:40)	1.2	0	0	0	
September	20	2018	21.2	25.0 (15:55)	19.2 (03:30)	1.4	0	0	0	
September	21	2018	21.6	24.0 (17:00)	19.2 (04:00)	1.7	0	0	0	
September	22	2018	20.8	24.0 (12:45)	15.4 (23:25)	1.7	0.3	0	0	
September	23	2018	15.9	16.8 (15:30)	15.2 (08:15)	1.1	21.1	0	0	
September	24	2018	17.2	19.3 (14:15)	15.9 (00:10)	2.5	3	0	0	
September	25	2018	21.2	26.4 (12:55)	16.0 (00:10)	1.4	2.5	0	0	
September	26	2018	24.3	29.2 (15:20)	20.8 (00:35)	1.7	7.4	0	0	
September	27	2018	18	21.3 (00:10)	14.4 (21:55)	1.6	1.5	0	0	
September	28	2018	17.4	21.8 (17:50)	14.3 (23:35)	1.1	25.1	0	0	
September	29	2018	17.9	24.6 (15:40)	11.9 (07:10)	0.8	0	0	0	

Month	Day	Year	Avg Temp	Max Temp	Min Temp	Avg Wind Speed	Rainfall	Supplemental Irrigation	Supplemental Irrigation (Sod)	Additional Notes
			(°C)	(°C)	(°C)	($m.s^{-1}$)	(mm)	(mm)	(mm)	
September	30	2018	17.1	23.6 (15:05)	11.3 (07:10)	0.7	0	0	0	Cool-season grasses resown in spring plots
October	1	2018	20	26.6 (15:35)	13.4 (06:35)	1.2	0	0	0	
October	2	2018	21.8	27.2 (12:50)	16.1 (07:05)	1.7	0	50.8 (Fall)	0	Fall plots sown.
October	3	2018	20.6	25.6 (16:15)	15.6 (23:55)	0.9	0	0	0	
October	4	2018	20.9	28.7 (15:35)	14.4 (02:55)	0.7	1.3	0	0	
October	5	2018	17.9	22.6 (01:10)	16.1 (12:45)	1.5	0.3	0	0	
October	6	2018	19.5	22.0 (14:15)	17.0 (01:15)	1	0.3	0	0	
October	7	2018	22.3	26.4 (17:15)	20.0 (24:00)	1	0	0	0	
October	8	2018	21.2	23.3 (13:30)	18.7 (03:50)	1.4	0.3	0	0	
October	9	2018	23.2	26.9 (14:10)	21.3 (06:55)	0.9	2.3	0	0	
October	10	2018	23.1	28.9 (14:30)	19.4 (04:20)	1	0	0	0	Sod over plastic sown.
October	11	2018	23.8	27.4 (15:05)	21.3 (00:40)	1.7	11.4	0	0	

Month	**Day**	**Year**	**Avg Temp**	**Max Temp**	**Min Temp**	**Avg Wind Speed**	**Rainfall**	**Supplemental Irrigation**	**Supplemental Irrigation (Sod)**	**Additional Notes**
			(°C)	**(°C)**	**(°C)**	**($m.s^{-1}$)**	**(mm)**	**(mm)**	**(mm)**	
October	12	2018	15.3	21.5 (00:25)	9.0 (24:00)	2.8	6.6	0	0	
October	13	2018	10.3	14.6 (16:30)	6.8 (24:00)	1.2	3	0	0	
October	14	2018	10.2	13.7 (17:00)	6.5 (05:10)	0.5	0.3	0	0	
October	15	2018	16.4	19.6 (17:10)	12.1 (00:05)	1.8	4.8	0	0	
October	16	2018	12.4	17.6 (00:05)	9.1 (23:25)	1.8	0.3	0	0	
October	17	2018	12.3	18.6 (16:00)	7.6 (06:50)	2	0	0	0	
October	18	2018	8.1	12.0 (16:15)	3.9 (23:10)	1.6	0	0	0	
October	19	2018	9.7	16.3 (15:10)	1.6 (05:45)	1.9	0	0	0	
October	20	2018	13.9	18.7 (16:00)	9.6 (21:40)	2	1.5	0	0	
October	21	2018	8.1	10.6 (15:00)	2.1 (23:55)	3	0.8	0	0	
October	22	2018	6.8	12.4 (15:15)	0.4 (07:35)	1.6	0	0	0	
October	23	2018	13.1	19.9 (15:55)	8.0 (00:30)	1.8	0	0	0	

Month	Day	Year	Avg Temp	Max Temp	Min Temp	Avg Wind Speed	Rainfall	Supplemental Irrigation	Supplemental Irrigation (Sod)	Additional Notes
			(°C)	(°C)	(°C)	(m.s^{-1})	(mm)	(mm)	(mm)	
October	24	2018	8.6	12.8 (14:10)	3.4 (23:40)	2.2	0	0	0	
October	25	2018	5.8	11.3 (14:40)	1.1 (07:25)	1.2	0	0	0	
October	26	2018	6.5	9.4 (15:10)	2.5 (06:30)	1.7	7.4	0	0	
October	27	2018	9.2	10.7 (11:20)	7.7 (24:00)	4	29	0	0	
October	28	2018	9.3	13.2 (12:55)	6.7 (20:05)	1.2	0.3	0	0	
October	29	2018	11	14.2 (12:50)	6.3 (23:25)	2.5	0.3	0	0	
October	30	2018	8.4	15.6 (16:35)	3.3 (06:05)	1.6	0	0	0	
October	31	2018	11.7	19.9 (15:20)	3.0 (03:45)	1.5	0.3	0	0	
November	1	2018	16.2	22.1 (16:15)	8.3 (07:05)	1.9	0	0	0	
November	2	2018	20.4	22.1 (13:30)	14.1 (24:00)	3.3	12.4	0	0	
November	3	2018	11.7	14.2 (14:15)	6.2 (24:00)	2.7	5.8	0	0	
November	4	2018	7.2	13.6 (15:10)	1.5 (06:30)	1	0	0	0	

Month	**Day**	**Year**	**Avg Temp**	**Max Temp**	**Min Temp**	**Avg Wind Speed**	**Rainfall**	**Supplemental Irrigation**	**Supplemental Irrigation (Sod)**	**Additional Notes**
			(°C)	**(°C)**	**(°C)**	**($m.s^{-1}$)**	**(mm)**	**(mm)**	**(mm)**	
November	5	2018	11	13.5 (12:10)	7.2 (00:05)	2.8	19.3	0	0	
November	6	2018	13.2	15.3 (11:05)	11.3 (03:25)	1.7	19.8	0	0	
November	7	2018	13.1	16.8 (12:30)	7.9 (06:55)	1.7	0.3	0	0	
November	8	2018	10.2	13.1 (01:10)	6.9 (24:00)	1.6	0	0	0	
November	9	2018	7.9	10.1 (12:25)	4.8 (04:15)	2.2	17.5	0	0	
November	10	2018	4.7	8.8 (01:10)	-0.7 (23:55)	3	0	0	0	
November	11	2018	1.8	7.8 (15:25)	-2.4 (06:25)	1.1	0	0	0	
November	12	2018	3.9	8.7 (13:15)	-2.6 (02:30)	0.7	7.6	0	0	
November	13	2018	7.3	9.3 (12:55)	5.7 (24:00)	2.3	21.6	0	0	
November	14	2018	3.7	6.1 (12:20)	1.4 (24:00)	2.3	0	0	0	
November	15	2018	0.8	4.3 (24:00)	-1.4 (13:25)	3.9	27.2	0	0	
November	16	2018	4.1	7.7 (12:45)	1.1 (23:10)	3.1	5.3	0	0	

Month	Day	Year	Avg Temp	Max Temp	Min Temp	Avg Wind Speed	Rainfall	Supplemental Irrigation	Supplemental Irrigation (Sod)	Additional Notes
			(°C)	(°C)	(°C)	($m.s^{-1}$)	(mm)	(mm)	(mm)	
November	17	2018	4.8	9.1 (13:35)	-0.5 (24:00)	1.5	0	0	0	
November	18	2018	3.2	8.7 (14:35)	-1.3 (04:00)	0.7	0	0	0	
November	19	2018	5.8	10.7 (15:40)	-0.5 (03:55)	0.5	0	0	0	
November	20	2018	6.6	9.8 (12:05)	2.5 (24:00)	2	0	0	0	
November	21	2018	4.1	9.7 (13:40)	-0.4 (06:45)	2.7	0	0	0	
November	22	2018	-3.2	1.4 (00:05)	-6.1 (24:00)	2.5	0	0	0	
November	23	2018	-4.3	1.1 (14:10)	-8.6 (06:45)	1.1	0	0	0	
November	24	2018	3.7	10.2 (19:45)	-4.3 (02:45)	2	61	0	0	
November	25	2018	8.1	14.7 (15:00)	3.2 (23:05)	1.5	0	0	0	
November	26	2018	8	11.2 (11:15)	3.5 (00:15)	1.9	19.6	0	0	
November	27	2018	3.4	5.8 (10:25)	1.5 (22:00)	3.2	0	0	0	
November	28	2018	2	3.5 (11:30)	1.4 (22:05)	4.2	0	0	0	

Month	Day	Year	Avg Temp	Max Temp	Min Temp	Avg Wind Speed	Rainfall	Supplemental Irrigation	Supplemental Irrigation (Sod)	Additional Notes
			(°C)	(°C)	(°C)	($m.s^{-1}$)	(mm)	(mm)	(mm)	
November	29	2018	2.3	5.6 (14:05)	-0.4 (20:50)	2.8	0	0	0	
November	30	2018	3.8	6.4 (14:30)	0.7 (06:55)	0.9	0	0	0	
December	1	2018	4	7.3 (12:10)	-1.4 (06:45)	1.4	5.3	0	0	
December	2	2018	10.7	13.2 (18:45)	6.5 (00:10)	1.4	13.5	0	0	
December	3	2018	10.8	13.8 (02:20)	5.9 (23:55)	2.6	0	0	0	
December	4	2018	3.2	6.3 (00:15)	-2.9 (24:00)	2.3	0	0	0	
December	5	2018	-1.3	1.4 (14:20)	-4.1 (03:30)	1	0	0	0	
December	6	2018	1.3	4.5 (14:25)	-3.4 (05:45)	2	0	0	0	
December	7	2018	1	4.2 (13:00)	-4.5 (24:00)	2	0	0	0	
December	8	2018	-2.1	3.1 (13:55)	-6.8 (05:30)	1.2	0	0	0	
December	9	2018	-1	0.7 (14:00)	-2.7 (06:50)	0.9	0	0	0	
December	10	2018	-0.8	4.0 (14:05)	-3.8 (23:20)	1.4	0	0	0	

Month	Day	Year	Avg Temp	Max Temp	Min Temp	Avg Wind Speed	Rainfall	Supplemental Irrigation	Supplemental Irrigation (Sod)	Additional Notes
			(°C)	**(°C)**	**(°C)**	**($m.s^{-1}$)**	**(mm)**	**(mm)**	**(mm)**	
December	11	2018	-1.3	5.2 (14:25)	-6.1 (07:05)	0.7	0	0	0	
December	12	2018	1.6	6.6 (14:55)	-2.5 (00:05)	1	0	0	0	
December	13	2018	4.5	9.7 (13:40)	-0.6 (01:10)	1.6	0	0	0	
December	14	2018	7.4	10.7 (14:10)	3.7 (00:25)	0.9	4.8	0	0	
December	15	2018	10	11.9 (14:30)	8.5 (22:20)	2.9	19.1	0	0	
December	16	2018	5.6	8.6 (00:40)	3.9 (23:30)	4.2	33.8	0	0	
December	17	2018	6	9.6 (15:15)	3.5 (07:30)	2.8	0	0	0	
December	18	2018	2.6	5.7 (14:50)	-3.1 (24:00)	2.6	0	0	0	
December	19	2018	0.4	8.2 (15:00)	-5.1 (07:00)	0.8	0	0	0	
December	20	2018	3.2	15.1 (23:50)	-3.1 (06:05)	1.7	21.8	0	0	
December	21	2018	12.8	14.8 (00:05)	8.4 (23:15)	2.8	17.8	0	0	
December	22	2018	6.6	10.1 (01:35)	4.8 (06:00)	3.7	0.5	0	0	

Month	**Day**	**Year**	**Avg Temp**	**Max Temp**	**Min Temp**	**Avg Wind Speed**	**Rainfall**	**Supplemental Irrigation**	**Supplemental Irrigation (Sod)**	**Additional Notes**
			(°C)	**(°C)**	**(°C)**	**($m.s^{-1}$)**	**(mm)**	**(mm)**	**(mm)**	
December	23	2018	4.7	7.6 (14:30)	2.0 (07:30)	1.2	0	0	0	
December	24	2018	4.4	6.9 (13:30)	1.5 (24:00)	2.1	1	0	0	
December	25	2018	1.2	5.0 (12:05)	-2.2 (24:00)	1.4	0	0	0	
December	26	2018	1.5	7.6 (14:55)	-2.9 (02:20)	1.1	0	0	0	
December	27	2018	2.8	8.4 (15:00)	-3.2 (07:35)	1.7	0.5	0	0	
December	28	2018	9.9	14.7 (13:30)	4.8 (00:05)	1.6	40.4	0	0	
December	29	2018	8.5	12.0 (05:45)	2.9 (23:50)	2.5	0	0	0	
December	30	2018	2.7	7.6 (14:15)	-0.7 (23:30)	0.7	0	0	0	
December	31	2018	3.7	10.1 (23:55)	-1.9 (05:10)	1.2	17.5	0	0	
January	1	2019	11.4	15.5 (10:25)	4.8 (23:30)	3.4	2.3	0	0	
January	2	2019	4.2	6.0 (14:15)	1.2 (07:15)	1.6	0	0	0	
January	3	2019	4.5	7.3 (12:30)	-1.8 (24:00)	1.5	0	0	0	

Month	Day	Year	Avg Temp (°C)	Max Temp (°C)	Min Temp (°C)	Avg Wind Speed (m.s^{-1})	Rainfall (mm)	Supplemental Irrigation (mm)	Supplemental Irrigation (Sod) (mm)	Additional Notes
January	4	2019	3	7.3 (15:30)	-2.4 (05:25)	0.9	1.8	0	0	
January	5	2019	6.9	7.9 (16:25)	5.6 (00:35)	2.4	6.3	0	0	
January	6	2019	6.6	10.8 (13:15)	2.4 (23:55)	2.4	0	0	0	
January	7	2019	0.1	2.4 (00:05)	-1.7 (06:55)	1.4	0	0	0	
January	8	2019	5.1	9.2 (15:40)	1.2 (02:20)	1	7.6	0	0	
January	9	2019	5	8.8 (00:25)	-0.4 (24:00)	4.1	0.3	0	0	
January	10	2019	0.4	2.7 (14:25)	-1.8 (24:00)	5.2	0	0	0	
January	11	2019	-1.8	1.6 (14:20)	-5.5 (23:40)	3.1	0	0	0	
January	12	2019	-3.1	0.9 (14:55)	-6.8 (06:35)	0.7	0	0	0	
January	13	2019	-2.1	-0.7 (15:25)	-3.4 (05:30)	2.4	2.5	0	0	
January	14	2019	-3.2	0.5 (14:45)	-6.7 (24:00)	1.7	1.3	0	0	
January	15	2019	-3.2	1.9 (14:00)	-8.0 (02:20)	1.2	0	0	0	

Month	Day	Year	Avg Temp	Max Temp	Min Temp	Avg Wind Speed	Rainfall	Supplemental Irrigation	Supplemental Irrigation (Sod)	Additional Notes
			(°C)	(°C)	(°C)	($m.s^{-1}$)	(mm)	(mm)	(mm)	
January	16	2019	-0.8	3.5 (15:55)	-7.9 (06:55)	1.1	0	0	0	
January	17	2019	-0.5	2.0 (00:05)	-3.9 (06:55)	1.5	0	0	0	
January	18	2019	0.7	3.6 (14:35)	-1.7 (01:30)	1.1	1.8	0	0	
January	19	2019	1.7	3.3 (24:00)	-0.1 (05:35)	2.1	17.3	0	0	
January	20	2019	1.1	9.0 (09:35)	-9.1 (24:00)	4.5	11.7	0	0	
January	21	2019	-9.8	-7.6 (15:15)	-12.4 (07:15)	5.8	0	0	0	
January	22	2019	-5.4	0.4 (16:00)	-10.5 (07:25)	1.7	0	0	0	
January	23	2019	3.6	13.1 (24:00)	-3.3 (01:25)	2.3	0	0	0	
January	24	2019	10	16.1 (10:45)	0.2 (24:00)	4.4	28.4	0	0	
January	25	2019	0.5	3.7 (11:55)	-3.3 (24:00)	2.1	0	0	0	
January	26	2019	-2.3	2.6 (14:25)	-7.6 (06:50)	0.7	0	0	0	
January	27	2019	1.6	7.1 (15:30)	-4.5 (05:00)	1.7	0	0	0	

Month	Day	Year	Avg Temp	Max Temp	Min Temp	Avg Wind Speed	Rainfall	Supplemental Irrigation	Supplemental Irrigation (Sod)	Additional Notes
			(°C)	(°C)	(°C)	($m.s^{-1}$)	(mm)	(mm)	(mm)	
January	28	2019	-1.3	2.3 (00:10)	-4.8 (23:05)	1.6	0	0	0	
January	29	2019	0	3.6 (14:05)	-4.3 (03:05)	1.7	7.6	0	0	
January	30	2019	-6.7	1.0 (13:55)	-14.0 (24:00)	3.9	0	0	0	
January	31	2019	-11.7	-7.8 (15:50)	-14.7 (05:00)	2	0	0	0	
February	1	2019	-9.9	-7.6 (15:40)	-12.5 (23:10)	0.9	0	0	0	
February	2	2019	-6.9	-1.0 (15:45)	-14.1 (03:55)	1.3	0.8	0	0	
February	3	2019	0.8	9.7 (16:10)	-6.7 (03:10)	0.6	0	0	0	
February	4	2019	4.8	15.7 (15:15)	-2.7 (05:55)	0.6	0.3	0	0	
February	5	2019	9	19.3 (14:20)	-0.7 (02:45)	1.1	0	0	0	
February	6	2019	6.1	9.7 (13:25)	1.9 (04:45)	1.8	12.2	0	0	
February	7	2019	6.3	10.2 (12:50)	4.3 (22:00)	1.7	1	0	0	
February	8	2019	6.1	12.9 (13:10)	0.2 (23:40)	3	1	0	0	

Month	Day	Year	Avg Temp	Max Temp	Min Temp	Avg Wind Speed	Rainfall	Supplemental Irrigation	Supplemental Irrigation (Sod)	Additional Notes
			(°C)	(°C)	(°C)	($m.s^{-1}$)	(mm)	(mm)	(mm)	
February	9	2019	-2.2	0.2 (00:05)	-5.0 (24:00)	3.4	0	0	0	
February	10	2019	-2.4	2.4 (14:00)	-8.0 (06:50)	1.1	0	0	0	
February	11	2019	-0.7	1.0 (11:25)	-2.2 (01:25)	1.3	2.3	0	0	
February	12	2019	1	3.5 (20:15)	-1.1 (02:35)	3.4	27.9	0	0	
February	13	2019	3.1	5.3 (11:10)	0.9 (24:00)	2.5	0.8	0	0	
February	14	2019	3.9	9.2 (16:00)	-0.9 (06:50)	1.9	0	0	0	
February	15	2019	10.9	16.5 (14:35)	1.3 (03:55)	3.1	0	0	0	
February	16	2019	3.8	9.1 (00:05)	-0.7 (22:35)	2.7	0	0	0	
February	17	2019	0	2.1 (16:25)	-3.3 (07:00)	1.9	6.3	0	0	
February	18	2019	3.5	7.4 (13:10)	0.6 (23:40)	3	4.3	0	0	
February	19	2019	-0.3	2.3 (14:55)	-2.9 (06:40)	2.2	0	0	0	
February	20	2019	-1	0.7 (24:00)	-3.2 (11:25)	1.7	0.3	0	0	

Month	Day	Year	Avg Temp	Max Temp	Min Temp	Avg Wind Speed	Rainfall	Supplemental Irrigation	Supplemental Irrigation (Sod)	Additional Notes
			(°C)	(°C)	(°C)	(m.s^{-1})	(mm)	(mm)	(mm)	
February	21	2019	5.4	11.7 (15:45)	0.5 (02:40)	1.5	10.2	0	0	
February	22	2019	5.8	7.8 (00:05)	1.9 (23:15)	1.6	0	0	0	
February	23	2019	2.9	4.6 (15:05)	1.1 (07:05)	2	0.8	0	0	
February	24	2019	5.8	9.9 (19:45)	2.8 (00:05)	2.7	9.9	0	0	
February	25	2019	3.7	6.5 (00:25)	-0.1 (23:55)	4.8	0.3	0	0	
February	26	2019	1.6	6.2 (15:25)	-2.4 (04:15)	2.3	0	0	0	
February	27	2019	-0.2	2.4 (14:30)	-3.4 (07:00)	2.7	0	0	0	
February	28	2019	2.2	4.6 (14:55)	0.4 (22:25)	2	0	0	0	
March	1	2019	0	1.4 (15:45)	-2.1 (06:55)	2.5	12.7	0	0	
March	2	2019	1.9	3.8 (17:00)	0.4 (07:00)	1.6	6.9	0	0	
March	3	2019	2.2	4.9 (13:30)	0.1 (18:05)	1.2	11.4	0	0	
March	4	2019	0.9	2.7 (16:35)	-2.7 (24:00)	3.1	14.5	0	0	

Month	Day	Year	Avg Temp (°C)	Max Temp (°C)	Min Temp (°C)	Avg Wind Speed ($m.s^{-1}$)	Rainfall (mm)	Supplemental Irrigation (mm)	Supplemental Irrigation (Sod) (mm)	Additional Notes
March	5	2019	-2.3	2.5 (15:55)	-6.0 (05:15)	2.1	0	0	0	
March	6	2019	-4.9	-2.3 (15:15)	-7.1 (06:45)	3.3	0	0	0	
March	7	2019	-2.1	2.7 (15:25)	-7.0 (01:55)	1.9	0	0	0	
March	8	2019	0	4.0 (13:35)	-5.3 (06:10)	1	0.3	0	0	
March	9	2019	3.5	8.7 (14:45)	0.9 (00:50)	1.5	0	0	0	
March	10	2019	6.2	9.2 (18:00)	2.1 (00:50)	1.8	21.3	0	0	
March	11	2019	8.9	13.8 (17:35)	4.2 (07:25)	2.4	0	0	0	
March	12	2019	4.5	8.0 (00:05)	-0.5 (23:50)	2.8	0	0	0	
March	13	2019	4	11.7 (15:50)	-3.3 (07:25)	1.7	0	0	0	
March	14	2019	10.6	20.1 (15:05)	1.7 (07:15)	1.8	0	0	0	
March	15	2019	18.4	24.5 (16:00)	10.9 (01:10)	4.7	4.1	0	0	
March	16	2019	7.9	13.9 (00:05)	3.2 (24:00)	4.5	0	0	0	

Month	**Day**	**Year**	**Avg Temp**	**Max Temp**	**Min Temp**	**Avg Wind Speed**	**Rainfall**	**Supplemental Irrigation**	**Supplemental Irrigation (Sod)**	**Additional Notes**
			(°C)	**(°C)**	**(°C)**	**($m.s^{-1}$)**	**(mm)**	**(mm)**	**(mm)**	
March	17	2019	3.6	8.3 (16:40)	-1.6 (05:55)	2	0	0	0	
March	18	2019	3.5	8.7 (16:50)	-0.8 (02:30)	1.3	0	0	0	
March	19	2019	4.4	9.9 (15:05)	-1.4 (06:45)	1.2	0	0	0	
March	20	2019	4.6	10.5 (14:55)	-2.5 (06:45)	1.8	0	0	0	
March	21	2019	8.3	10.6 (16:55)	5.4 (04:20)	3.2	48.3	0	0	
March	22	2019	6.9	10.6 (15:25)	4.0 (06:25)	5.4	8.9	0	0	
March	23	2019	5.4	10.3 (17:30)	1.3 (07:15)	4.8	0	0	0	
March	24	2019	8.8	16.1 (15:50)	-2.1 (06:55)	2	0	0	0	
March	25	2019	8.8	15.0 (12:10)	4.3 (23:30)	1.8	3.3	0	0	
March	26	2019	4.8	8.8 (17:10)	0.6 (07:10)	2.6	0	0	0	
March	27	2019	4	10.1 (16:00)	-3.1 (07:05)	1.7	0	0	0	
March	28	2019	6	14.7 (15:40)	-2.6 (06:25)	1.7	0	0	0	

Month	Day	Year	Avg Temp	Max Temp	Min Temp	Avg Wind Speed	Rainfall	Supplemental Irrigation	Supplemental Irrigation (Sod)	Additional Notes
			(°C)	(°C)	(°C)	($m.s^{-1}$)	(mm)	(mm)	(mm)	
March	29	2019	12.2	17.9 (17:15)	6.2 (03:25)	0.9	0	0	0	
March	30	2019	16.2	24.2 (14:25)	8.6 (04:20)	2.4	0	0	0	
March	31	2019	12.1	16.7 (08:45)	1.8 (24:00)	4.4	2.5	0	0	
April	1	2019	3	7.8 (17:20)	-0.4 (06:50)	3.6	0	0	0	
April	2	2019	4.7	9.9 (16:20)	-2.6 (06:40)	1.9	0	0	0	
April	3	2019	11.2	19.6 (15:55)	2.0 (06:55)	3	0	0	0	
April	4	2019	11.7	18.2 (17:15)	4.1 (06:50)	1.3	0	0	0	
April	5	2019	7.5	11.2 (02:10)	5.5 (20:55)	3.5	1	0	0	
April	6	2019	11.4	19.3 (16:45)	5.1 (05:00)	1.3	0.3	0	0	
April	7	2019	13.5	20.6 (14:20)	5.5 (06:50)	1.8	0.8	0	0	
April	8	2019	19.2	27.1 (15:20)	11.1 (04:55)	2.1	1.3	0	0	
April	9	2019	19.2	23.7 (17:30)	15.1 (24:00)	2.3	0	0	0	

Month	Day	Year	Avg Temp	Max Temp	Min Temp	Avg Wind Speed	Rainfall	Supplemental Irrigation	Supplemental Irrigation (Sod)	Additional Notes
			(°C)	(°C)	(°C)	($m.s^{-1}$)	(mm)	(mm)	(mm)	
April	10	2019	13.7	17.9 (16:20)	7.8 (06:45)	2.6	0	0	12.7	
April	11	2019	9.5	13.6 (15:35)	5.9 (06:40)	3.1	0	0	0	
April	12	2019	14.7	24.0 (14:00)	8.1 (00:15)	2.2	6.6	0	0	
April	13	2019	19.1	23.6 (14:15)	15.2 (00:35)	1.6	2.5	0	0	
April	14	2019	18.3	23.8 (16:55)	13.2 (03:25)	1.9	0.5	0	0	
April	15	2019	13.9	23.3 (00:50)	7.3 (24:00)	4.6	11.9	0	0	
April	16	2019	12.3	18.8 (17:10)	4.6 (06:20)	2.3	0	0	0	
April	17	2019	13.4	16.5 (15:45)	11.1 (24:00)	2.8	0	0	0	
April	18	2019	18.3	25.3 (18:25)	10.9 (01:05)	2.7	0	0	12.7	
April	19	2019	21	24.6 (13:10)	18.6 (06:50)	3.6	5.8	0	0	
April	20	2019	19.2	23.2 (15:00)	15.0 (22:25)	3.1	11.9	0	0	
April	21	2019	15.7	20.0 (16:15)	11.7 (06:15)	1.3	0	0	0	

Month	**Day**	**Year**	**Avg Temp**	**Max Temp**	**Min Temp**	**Avg Wind Speed**	**Rainfall**	**Supplemental Irrigation**	**Supplemental Irrigation (Sod)**	**Additional Notes**
			(°C)	**(°C)**	**(°C)**	**($m.s^{-1}$)**	**(mm)**	**(mm)**	**(mm)**	
April	22	2019	16.1	20.4 (16:00)	11.5 (02:05)	2	0	0	0	
April	23	2019	19	25.6 (16:40)	10.4 (06:35)	1.6	0	0	0	
April	24	2019	17.9	21.8 (17:10)	12.0 (23:55)	2.2	0	0	0	
April	25	2019	15.8	20.3 (16:35)	11.5 (00:40)	1.6	0	0	0	
April	26	2019	15.3	22.6 (15:40)	12.1 (24:00)	2.4	27.2	0	0	
April	27	2019	14.4	19.2 (17:20)	9.9 (05:25)	3.5	0	0	0	
April	28	2019	13.5	20.5 (15:25)	7.7 (24:00)	1.8	0.3	0	0	
April	29	2019	10.1	15.5 (14:35)	2.5 (06:25)	2.2	0	0	0	
April	30	2019	16.5	23.5 (17:20)	10.1 (00:05)	1.7	0.3	0	0	
May	1	2019	13.8	16.0 (16:05)	11.7 (04:35)	2.9	0	0	12.7	
May	2	2019	19.1	27.8 (15:45)	12.8 (05:00)	1	0	0	0	
May	3	2019	15.2	19.8 (17:55)	11.6 (07:35)	2.2	0	0	0	

Month	Day	Year	Avg Temp	Max Temp	Min Temp	Avg Wind Speed	Rainfall	Supplemental Irrigation	Supplemental Irrigation (Sod)	Additional Notes
			(°C)	(°C)	(°C)	($m.s^{-1}$)	(mm)	(mm)	(mm)	
May	4	2019	18.1	23.1 (16:30)	14.5 (04:30)	1.1	1	0	0	
May	5	2019	14.5	17.9 (00:10)	12.1 (23:45)	2.8	30.5	0	0	
May	6	2019	16.3	23.3 (18:15)	12.2 (24:00)	1.4	0	0	0	
May	7	2019	16.5	24.1 (16:10)	11.9 (02:10)	1.3	0	0	0	
May	8	2019	16.7	18.2 (16:45)	15.0 (12:50)	1.8	0	0	0	
May	9	2019	16.1	19.7 (17:10)	14.4 (10:50)	2.8	1.5	0	0	
May	10	2019	19.5	25.5 (15:25)	14.3 (05:45)	2	2.8	0	0	
May	11	2019	17.3	19.7 (15:40)	12.6 (24:00)	1.5	6.6	0	0	
May	12	2019	10.2	12.5 (00:05)	7.9 (23:35)	4.6	27.9	0	0	
May	13	2019	9.1	11.6 (16:25)	7.6 (06:25)	2.6	24.9	0	0	
May	14	2019	10.8	14.4 (16:50)	8.1 (23:35)	1.5	0.3	0	0	
May	15	2019	14.7	22.6 (16:50)	5.7 (06:05)	1.5	0	0	0	

Month	Day	Year	Avg Temp	Max Temp	Min Temp	Avg Wind Speed	Rainfall	Supplemental Irrigation	Supplemental Irrigation (Sod)	Additional Notes
			(°C)	(°C)	(°C)	($m.s^{-1}$)	(mm)	(mm)	(mm)	
May	16	2019	17.8	23.3 (18:10)	12.7 (04:40)	1.5	0.5	0	0	
May	17	2019	19.8	26.8 (16:45)	11.3 (05:50)	1.6	0	0	12.7	
May	18	2019	19.8	25.0 (17:45)	16.2 (04:35)	1.5	0	0	0	
May	19	2019	22.5	29.9 (17:15)	14.5 (05:55)	1.5	0	0	0	
May	20	2019	25.9	30.7 (14:45)	22.2 (23:20)	2.6	0	0	12.7	
May	21	2019	18.1	22.5 (00:05)	13.0 (23:20)	2.3	0	0	12.7	
May	22	2019	17.1	22.8 (15:30)	8.2 (05:50)	1.3	0	0	0	
May	23	2019	19.5	25.0 (18:15)	14.5 (06:35)	1.9	0.8	0	12.7	
May	24	2019	23.1	27.1 (16:55)	20.0 (03:25)	2.5	0	0	0	
May	25	2019	18.6	22.1 (15:55)	16.0 (05:30)	2.5	0	0	12.7	
May	26	2019	23.4	30.1 (17:20)	16.3 (04:05)	1.4	8.6	0	0	
May	27	2019	22.5	27.3 (16:15)	16.7 (24:00)	1.3	0.3	0	0	

Month	**Day**	**Year**	**Avg Temp**	**Max Temp**	**Min Temp**	**Avg Wind Speed**	**Rainfall**	**Supplemental Irrigation**	**Supplemental Irrigation (Sod)**	**Additional Notes**
			(°C)	**(°C)**	**(°C)**	**($m.s^{-1}$)**	**(mm)**	**(mm)**	**(mm)**	
May	28	2019	21.2	28.9 (16:55)	15.5 (03:50)	1.8	8.4	0	0	
May	29	2019	24.3	31.6 (15:15)	19.6 (05:50)	1.9	14.2	0	0	
May	30	2019	22.9	29.1 (15:00)	19.4 (03:55)	1.4	20.6	0	0	
May	31	2019	22.4	27.0 (17:55)	18.0 (05:40)	1.4	0	0	0	
June	1	2019	22.2	28.4 (16:05)	16.2 (04:25)	1	0	0	0	
June	2	2019	21.8	27.4 (16:10)	16.2 (05:50)	1.5	1.8	0	0	
June	3	2019	17.8	21.8 (14:00)	12.3 (05:55)	1.8	0	0	12.7	Sod over plastic transplanted.
June	4	2019	16.9	21.9 (17:20)	9.4 (05:55)	1.6	0	0	12.7	
June	5	2019	22.4	27.1 (16:55)	15.5 (06:00)	2.5	4.3	0	12.7	
June	6	2019	24.9	29.2 (14:00)	20.8 (04:25)	1.6	0.5	0	12.7	
June	7	2019	23.4	26.8 (15:50)	19.6 (23:50)	1.4	0	0	12.7	
June	8	2019	22.1	27.2 (16:30)	16.8 (05:20)	2.5	0	0	12.7	

Month	Day	Year	Avg Temp	Max Temp	Min Temp	Avg Wind Speed	Rainfall	Supplemental Irrigation	Supplemental Irrigation (Sod)	Additional Notes
			(°C)	(°C)	(°C)	(m.s^{-1})	(mm)	(mm)	(mm)	
June	9	2019	21.3	26.8 (15:20)	16.7 (06:30)	3.9	0	0	0	
June	10	2019	20.1	24.4 (15:15)	15.7 (02:30)	2	69.3	0	0	
June	11	2019	21.3	25.6 (16:40)	17.1 (22:30)	2.3	1	0	0	
June	12	2019	19.3	23.1 (13:55)	13.0 (05:35)	2.1	0	0	0	
June	13	2019	17.8	22.7 (17:30)	14.7 (07:50)	2.2	47.8	0	0	
June	14	2019	18	23.0 (17:55)	13.2 (04:35)	2.5	0.5	0	0	
June	15	2019	19.7	26.3 (15:40)	10.8 (05:40)	2.3	0	0	12.7	
June	16	2019	23.6	27.5 (14:30)	20.1 (05:50)	2.3	0	0	0	
June	17	2019	24.4	29.8 (16:30)	21.2 (06:00)	0.9	8.6	0	0	
June	18	2019	24.1	28.5 (18:30)	20.9 (03:10)	1.3	3.8	0	12.7	
June	19	2019	24.6	29.0 (16:25)	21.6 (06:10)	1.5	41.1	0	0	
June	20	2019	25.1	29.4 (18:20)	22.1 (06:30)	1.6	15.7	0	12.7	

Month	Day	Year	Avg Temp (°C)	Max Temp (°C)	Min Temp (°C)	Avg Wind Speed ($m.s^{-1}$)	Rainfall (mm)	Supplemental Irrigation (mm)	Supplemental Irrigation (Sod) (mm)	Additional Notes
June	21	2019	22.9	26.4 (17:05)	19.7 (22:55)	2.4	2.3	0	0	
June	22	2019	21.7	26.7 (17:15)	15.8 (04:55)	1.7	0	0	12.7	
June	23	2019	21.9	27.5 (15:40)	14.5 (04:55)	1.4	0	0	0	
June	24	2019	23.9	29.6 (16:15)	16.0 (05:45)	1.2	0	0	0	
June	25	2019	26.1	30.5 (15:40)	22.7 (05:50)	1.5	0	0	12.7	
June	26	2019	25.6	30.8 (16:35)	18.1 (05:50)	1	0	0	12.7	
June	27	2019	26.9	32.7 (17:15)	20.9 (06:05)	0.9	0	0	0	
June	28	2019	26	32.7 (14:45)	19.9 (05:55)	1	0.3	0	12.7	
June	29	2019	24.8	32.4 (13:05)	20.5 (16:30)	1.4	14	0	0	
June	30	2019	25.8	30.3 (16:25)	21.4 (23:55)	2.1	0	0	0	
July	1	2019	22.5	28.0 (17:15)	15.8 (06:00)	1	0	0	12.7	
July	2	2019	24.5	31.7 (17:40)	18.0 (03:25)	1.7	22.4	0	0	

Month	**Day**	**Year**	**Avg Temp**	**Max Temp**	**Min Temp**	**Avg Wind Speed**	**Rainfall**	**Supplemental Irrigation**	**Supplemental Irrigation (Sod)**	**Additional Notes**
			(°C)	**(°C)**	**(°C)**	**($m.s^{-1}$)**	**(mm)**	**(mm)**	**(mm)**	
July	3	2019	26.2	31.1 (16:50)	21.6 (00:05)	1	0	0	0	
July	4	2019	26.7	32.1 (14:35)	21.9 (05:25)	1.2	0	0	0	
July	5	2019	26.2	31.3 (15:10)	23.3 (04:30)	1.2	8.4	0	0	
July	6	2019	26.4	31.6 (14:00)	22.8 (20:50)	1.4	13.2	0	12.7	
July	7	2019	25.3	30.0 (15:40)	21.7 (05:25)	1.5	0.3	0	0	
July	8	2019	22.5	25.3 (17:40)	19.8 (23:55)	2	4.8	0	0	
July	9	2019	23.9	30.4 (15:15)	17.9 (05:45)	0.9	0	0	0	
July	10	2019	25.1	29.8 (16:05)	19.5 (04:45)	1.4	0	0	0	
July	11	2019	23.6	29.2 (12:35)	20.0 (03:40)	1	32.5	0	0	
July	12	2019	25.7	30.7 (17:05)	21.3 (05:55)	1.4	0	0	0	
July	13	2019	24.8	30.0 (18:05)	18.2 (05:55)	1	0	0	0	
July	14	2019	26.7	32.0 (15:30)	20.7 (05:35)	1.2	0	0	0	

Month	Day	Year	Avg Temp	Max Temp	Min Temp	Avg Wind Speed	Rainfall	Supplemental Irrigation	Supplemental Irrigation (Sod)	Additional Notes
			(°C)	(°C)	(°C)	($m.s^{-1}$)	(mm)	(mm)	(mm)	
July	15	2019	24.6	29.8 (17:05)	18.1 (06:05)	0.9	0	0	0	
July	16	2019	26.2	32.4 (17:05)	18.3 (05:45)	1	0	0	0	
July	17	2019	28	33.9 (15:40)	22.8 (19:45)	1.4	12.2	0	0	
July	18	2019	26.3	31.0 (11:30)	23.2 (02:45)	0.7	2	0	0	
July	19	2019	28.6	33.3 (16:25)	23.5 (03:20)	1.2	0	0	0	
July	20	2019	30.3	34.7 (16:10)	25.8 (06:10)	1.2	0	0	0	
July	21	2019	30.5	35.1 (15:10)	24.9 (23:10)	1.4	0	0	0	
July	22	2019	26.5	32.6 (15:40)	21.0 (17:10)	1.3	18.5	0	0	
July	23	2019	22.1	24.7 (16:45)	19.9 (05:40)	1.3	13.5	0	0	
July	24	2019	23.1	28.4 (15:40)	17.8 (06:30)	1.2	0	0	0	
July	25	2019	23.4	29.2 (15:15)	17.5 (05:55)	1	0	0	0	
July	26	2019	23.9	30.5 (16:35)	16.9 (04:50)	0.7	0	0	0	

Month	Day	Year	Avg Temp	Max Temp	Min Temp	Avg Wind Speed	Rainfall	Supplemental Irrigation	Supplemental Irrigation (Sod)	Additional Notes
			(°C)	(°C)	(°C)	($m.s^{-1}$)	(mm)	(mm)	(mm)	
July	27	2019	24.9	30.6 (14:25)	17.7 (05:30)	0.9	0	0	0	
July	28	2019	26.4	31.9 (16:35)	20.1 (06:15)	1.3	0	0	0	
July	29	2019	27.7	32.7 (15:40)	22.3 (05:25)	1.1	0	0	0	
July	30	2019	28	33.6 (15:45)	23.6 (00:10)	1.6	0	0	0	
July	31	2019	26.4	31.0 (15:55)	21.3 (06:05)	1	0	0	0	
August	1	2019	24.8	30.5 (15:55)	21.1 (06:35)	0.8	7.6	0	0	
August	2	2019	24.3	29.5 (14:55)	20.7 (05:25)	1	0	0	0	
August	3	2019	25.2	31.4 (16:45)	19.6 (05:05)	0.7	0	0	0	
August	4	2019	26	31.4 (16:35)	21.3 (06:20)	0.9	0	0	0	
August	5	2019	25.1	31.1 (15:10)	20.5 (04:05)	0.9	0	0	0	
August	6	2019	25.5	31.6 (15:05)	21.8 (01:50)	0.9	0	0	0	
August	7	2019	25.2	32.8 (15:20)	20.4 (23:25)	1.2	2.3	0	0	

Month	Day	Year	Avg Temp	Max Temp	Min Temp	Avg Wind Speed	Rainfall	Supplemental Irrigation	Supplemental Irrigation (Sod)	Additional Notes
			(°C)	(°C)	(°C)	($m.s^{-1}$)	(mm)	(mm)	(mm)	
August	8	2019	24.5	31.2 (16:55)	19.5 (06:25)	1.2	1.8	0	0	
August	9	2019	24.6	30.3 (16:10)	18.6 (24:00)	1.1	0	0	0	
August	10	2019	22.6	28.8 (16:10)	14.8 (05:55)	1.2	0	0	0	
August	11	2019	21.6	27.5 (16:15)	14.9 (06:35)	0.9	0	0	0	
August	12	2019	23.5	30.4 (15:45)	14.3 (06:05)	1.2	0	0	0	
August	13	2019	24.4	26.1 (14:25)	22.7 (21:50)	1.1	0.3	0	0	
August	14	2019	24.1	28.8 (16:45)	21.8 (06:25)	1	13.5	0	0	
August	15	2019	24.1	29.1 (15:50)	20.2 (05:50)	1.3	0	0	0	
August	16	2019	25.1	29.8 (17:10)	21.2 (05:30)	1.1	0	0	0	
August	17	2019	26.7	31.4 (14:05)	23.3 (24:00)	1.1	0	0	0	
August	18	2019	25.4	32.3 (12:45)	20.5 (15:40)	0.9	7.4	0	0	
August	19	2019	27.2	33.2 (14:00)	21.8 (06:40)	0.8	0	0	0	

Month	Day	Year	Avg Temp	Max Temp	Min Temp	Avg Wind Speed	Rainfall	Supplemental Irrigation	Supplemental Irrigation (Sod)	Additional Notes
			(°C)	(°C)	(°C)	($m.s^{-1}$)	(mm)	(mm)	(mm)	
August	20	2019	27	33.1 (15:30)	21.9 (06:30)	0.9	7.1	0	0	
August	21	2019	26.3	32.0 (16:30)	20.9 (06:40)	1.7	0	0	0	
August	22	2019	26.8	32.6 (15:40)	20.9 (06:05)	1.2	6.1	0	0	
August	23	2019	20	22.0 (06:35)	17.4 (13:50)	1	7.6	0	0	
August	24	2019	19.8	25.8 (16:25)	14.8 (06:30)	1.6	0	0	0	
August	25	2019	19.5	24.8 (16:20)	13.5 (04:40)	2.1	0	0	0	
August	26	2019	18.6	21.7 (17:25)	14.8 (03:55)	1.7	0	0	0	
August	27	2019	19.4	25.2 (17:20)	13.8 (04:35)	0.8	0	0	0	
August	28	2019	22.3	28.2 (14:20)	18.7 (06:15)	1.1	0	0	0	
August	29	2019	22	27.5 (15:55)	15.6 (23:45)	1.5	0	0	0	
August	30	2019	22.5	30.4 (16:15)	13.9 (03:25)	1.4	0	0	0	
August	31	2019	23.3	29.2 (15:50)	17.5 (04:35)	1.3	0	0	0	

Month	**Day**	**Year**	**Avg Temp**	**Max Temp**	**Min Temp**	**Avg Wind Speed**	**Rainfall**	**Supplemental Irrigation**	**Supplemental Irrigation (Sod)**	**Additional Notes**
			(°C)	**(°C)**	**(°C)**	**($m.s^{-1}$)**	**(mm)**	**(mm)**	**(mm)**	
September	1	2019	21.9	28.0 (16:25)	16.9 (03:40)	1.6	0	0	0	
September	2	2019	23.3	29.9 (16:10)	19.1 (01:30)	1.5	0.3	0	0	
September	3	2019	23.6	30.6 (16:30)	18.5 (06:25)	1.2	0	0	0	
September	4	2019	25.6	32.6 (15:55)	18.7 (02:15)	2	0	0	0	
September	5	2019	22	25.0 (15:45)	19.1 (06:45)	2.1	0	0	0	
September	6	2019	18.3	20.1 (11:20)	15.2 (24:00)	2.5	1.5	0	0	
September	7	2019	19.3	26.4 (16:00)	12.0 (06:50)	1.3	0	0	0	
September	8	2019	20.9	27.9 (15:05)	12.8 (06:40)	0.9	0	0	0	
September	9	2019	21.8	28.9 (15:30)	17.1 (00:25)	0.6	0	0	0	
September	10	2019	22.3	28.1 (13:55)	16.7 (04:35)	1.2	0	0	0	
September	11	2019	24.6	31.3 (16:30)	18.7 (02:50)	1.3	0	0	0	
September	12	2019	25.5	32.0 (15:25)	20.2 (24:00)	1.8	14	0	0	

Month	Day	Year	Avg Temp	Max Temp	Min Temp	Avg Wind Speed	Rainfall	Supplemental Irrigation	Supplemental Irrigation (Sod)	Additional Notes
			(°C)	**(°C)**	**(°C)**	**($m.s^{-1}$)**	**(mm)**	**(mm)**	**(mm)**	
September	13	2019	18.8	20.8 (16:05)	15.9 (24:00)	3.1	0.3	0	0	
September	14	2019	20.3	25.9 (15:40)	13.8 (06:45)	1	2.5	0	0	
September	15	2019	23.1	28.9 (16:50)	17.0 (23:55)	0.8	0	0	0	
September	16	2019	22.8	29.4 (16:15)	15.6 (03:35)	0.8	0	0	0	
September	17	2019	21.4	26.0 (15:40)	14.1 (24:00)	1.8	0	0	0	
September	18	2019	17.3	23.8 (16:05)	11.0 (06:45)	1.3	0	0	0	
September	19	2019	14.9	22.3 (17:35)	9.1 (06:30)	0.9	0	0	0	
September	20	2019	16.1	24.8 (16:00)	7.7 (07:00)	1.1	0	0	0	
September	21	2019	19.7	30.2 (16:40)	10.3 (05:20)	0.6	0	0	0	
September	22	2019	22.6	31.7 (15:15)	14.5 (05:10)	0.9	0	0	0	
September	23	2019	25.8	32.3 (15:15)	19.4 (07:15)	1.9	0	0	0	
September	24	2019	21.1	25.6 (16:20)	15.4 (24:00)	1.3	0	0	0	

Month	Day	Year	Avg Temp	Max Temp	Min Temp	Avg Wind Speed	Rainfall	Supplemental Irrigation	Supplemental Irrigation (Sod)	Additional Notes
			(°C)	**(°C)**	**(°C)**	**($m.s^{-1}$)**	**(mm)**	**(mm)**	**(mm)**	
September	25	2019	18.9	26.7 (14:50)	10.8 (06:20)	1	0	0	0	
September	26	2019	19.7	29.2 (13:10)	13.1 (02:35)	1.1	0	0	0	
September	27	2019	18.9	26.7 (15:05)	10.8 (06:55)	1.1	0	0	0	
September	28	2019	21.3	28.9 (16:10)	13.3 (05:55)	1.2	0.8	0	0	
September	29	2019	23.3	27.6 (17:00)	19.8 (05:45)	1.2	0.3	0	0	
September	30	2019	19.9	23.1 (13:35)	17.9 (08:25)	1.8	0	0	0	

Appendix C

ANOVA TABLES

Table 11 ANOVA table for the mean % germination with the variables of sowing time (sowing), rate of seed (rate), and the seed mix (mix).

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Sowing	1	1	0.04796134	26.2007	<.0001*
Rate	2	2	0.05444785	14.8721	<.0001*
Sowing*Rate	2	2	0.01973881	5.3915	0.0090*
Mix	1	1	0.13098763	71.5569	<.0001*
Sowing*Mix	1	1	0.02383656	13.0216	0.0009*
Rate*Mix	2	2	0.01610789	4.3998	0.0195*
Sowing*Rate*Mix	2	2	0.00937402	2.5605	0.0913

Table 12 ANOVA table for the mean % grass coverage within two weeks of the final germination estimate with the variables of sowing time (sowing), rate of seed (rate), and the seed mix (mix).

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Sowing	1	1	1.4093880	30.5084	<.0001*
Rate	2	2	0.1509448	1.6337	0.2093
Sowing*Rate	2	2	0.2083635	2.2552	0.1195
Mix	1	1	0.0109505	0.2370	0.6293
Sowing*Mix	1	1	0.0360255	0.7798	0.3831
Rate*Mix	2	2	0.0070510	0.0763	0.9267
Sowing*Rate*Mix	2	2	0.0157198	0.1701	0.8442

Table 13 ANOVA table for the mean % forb coverage within two weeks of the final germination estimate with the variables of sowing time (sowing), rate of seed (rate), and the seed mix (mix).

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Sowing	1	1	3.1878521	222.1016	<.0001*
Rate	2	2	0.4483156	15.6174	<.0001*
Sowing*Rate	2	2	0.4762698	16.5912	<.0001*
Mix	1	1	0.0006021	0.0419	0.8389
Sowing*Mix	1	1	0.0003521	0.0245	0.8764
Rate*Mix	2	2	0.0140198	0.4884	0.6176
Sowing*Rate*Mix	2	2	0.0530073	1.8465	0.1724

Table 14 ANOVA table for the mean % empty space/weed coverage within two weeks of the final germination estimate with the variables of sowing time (sowing), rate of seed (rate), and the seed mix (mix).

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Sowing	1	1	0.35793802	7.3171	0.0104*
Rate	2	2	0.99731667	10.1937	0.0003*
Sowing*Rate	2	2	0.23030417	2.3540	0.1095
Mix	1	1	0.00641719	0.1312	0.7193
Sowing*Mix	1	1	0.04350052	0.8892	0.3520
Rate*Mix	2	2	0.02883750	0.2948	0.7465
Sowing*Rate*Mix	2	2	0.07871667	0.8046	0.4552

Table 15 ANOVA table for the mean rating of spontaneous vegetation between the first and second year of the spring sown plots with the variables of year, and native status of the vegetation (status).

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Year	1	1	8.7043956	5.6100	0.0191*
Status	1	1	0.1211538	0.0781	0.7803
Year*Status	1	1	3.2043956	2.0652	0.1527

Table 16 ANOVA table for the mean rating of spontaneous vegetation between the first year of the spring and fall sown plots with the variables of sowing time (sowing), and native status of the vegetation (status).

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Sowing	1	1	14.741786	7.5174	0.0068*
Status	1	1	0.546360	0.2786	0.5984
Sowing*Status	1	1	1.991133	1.0154	0.3152

Table 17 ANOVA table for the mean richness of the first year of the fall and spring sown plots with the variables of sowing time (sowing), rate of seed (rate), and the seed mix (mix).

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Sowing	1	1	0.31037136	66.9548	<.0001*
Mix	1	1	0.00650119	1.4025	0.2441
Sowing *Mix	1	1	0.00155910	0.3363	0.5656
Rate	2	2	0.03261048	3.5174	0.0402*
Sowing *Rate	2	2	0.00500105	0.5394	0.5877
Mix*Rate	2	2	0.00243807	0.2630	0.7702
Sowing *Mix*Rate	2	2	0.01697423	1.8309	0.1749

Table 18 ANOVA table for the mean richness between the first and second year of the spring sown plots with the variables of year, rate of seed (rate), and the seed mix (mix).

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mix	1	1	0.01450753	2.9140	0.0964
Rate	2	2	0.05685213	5.7097	0.0070*
Mix*Rate	2	2	0.01633489	1.6405	0.2080
Month/year	1	1	0.00360693	0.7245	0.4003
Mix*Month/year	1	1	0.00628892	1.2632	0.2685
Rate*Month/year	2	2	0.00373602	0.3752	0.6898
Mix*Rate*Month/year	2	2	0.00593908	0.5965	0.5561

Table 19 ANOVA table for the mean value of 1-D in Simpson's Diversity Index for the month of July for the first year of the fall and spring sown plots with the variables of sowing time (sowing), rate of seed (rate), and the seed mix (mix).

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Sowing	1	1	0.01689386	1.5214	0.2254
Mix	1	1	0.02362230	2.1273	0.1534
Sowing *Mix	1	1	0.00697721	0.6283	0.4332
Rate	2	2	0.02654284	1.1952	0.3144
Sowing *Rate	2	2	0.04762884	2.1446	0.1318
Mix*Rate	2	2	0.00787957	0.3548	0.7037
Sowing *Mix*Rate	2	2	0.00094196	0.0424	0.9585

Table 20 ANOVA table for the mean value of 1-D in Simpson's Diversity Index for the month of July for the first and second year of the spring sown plots with the variable of year, rate of seed (rate), and the seed mix (mix).

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mix	1	1	0.00197154	0.3781	0.5425
Rate	2	2	0.02774118	2.6599	0.0837
Mix*Rate	2	2	0.00453643	0.4350	0.6506
Year	1	1	0.00037988	0.0728	0.7888
Mix*Year	1	1	0.00066377	0.1273	0.7233
Rate*Year	2	2	0.00788129	0.7557	0.4770
Mix*Rate*Year	2	2	0.00222748	0.2136	0.8087

Table 21 ANOVA table for the mean % grass coverage in the month of June, after grasses had been resown in the spring sown plots. The variables included in this model are the seed mix (mix), rate of seed (rate), and season of sowing.

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Sowing	1	1	0.21067500	3.8738	0.0568
Mix	1	1	0.01050208	0.1931	0.6630
Sowing*Mix	1	1	0.03685208	0.6776	0.4158
Rate	2	2	0.14265938	1.3116	0.2820
Sowing*Rate	2	2	0.24362187	2.2398	0.1211
Mix*Rate	2	2	0.04010729	0.3687	0.6942
Sowing*Mix*Rate	2	2	0.00341979	0.0314	0.9691

Table 22 ANOVA table for the mean frequency of flower visitation in the spring sown plots with the variables of the seed mix (mix), rate of seed (rate), sunlight, wind speed, and temperature (temp).

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mix	1	1	112.99769	9.0548	0.0026*
Rate	2	2	21.34638	0.8553	0.4252
Mix*Rate	2	2	64.19248	2.5720	0.0765
Temp	1	1	40.61209	3.2544	0.0713
Sunlight	3	3	110.85240	2.9610	0.0310*
Temp*Sunlight	3	3	74.93566	2.0016	0.1115
Wind Speed (m/s)	1	1	182.16725	14.5975	0.0001*
Temp*Wind Speed (m/s)	1	1	8.40569	0.6736	0.4118
Sunlight*Wind Speed (m/s)	3	3	121.91795	3.2565	0.0207*
Temp*Sunlight*Wind Speed (m/s)	3	3	131.62127	3.5157	0.0145*

Table 23 ANOVA table for the mean frequency of flower visitation in the spring sown plots with the variables of the week of observation (week), time of day of observation (time of day), inflorescence rating (inflorescence), and the number of forbs in flower (forbs in flower) and plant species (plant).

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Week	1	1	438.2808	39.3068	<.0001*
Time of Day	2	2	251.4804	11.2769	<.0001*
Week*Time of Day	2	2	47.9210	2.1489	0.1167
Infloresence	1	1	960.5997	86.1506	<.0001*
Week*Infloresence	1	1	24.8368	2.2275	0.1356
Time of Day*Infloresence	2	2	48.0976	2.1568	0.1158
Week*Time of Day*Infloresence	2	2	11.2641	0.5051	0.6035
Forbs in Flower	1	1	0.1491	0.0134	0.9079
Week*Forbs in Flower	1	1	3.6918	0.3311	0.5650
Time of Day*Forbs in Flower	2	2	29.6086	1.3277	0.2652
Week*Time of Day*Forbs in Flower	2	2	107.5502	4.8228	0.0081*
Infloresence*Forbs in Flower	1	1	27.4415	2.4611	0.1168
Week*Infloresence*Forbs in Flower	1	1	6.0154	0.5395	0.4627
Time of Day*Infloresence*Forbs in Flower	2	2	8.9797	0.4027	0.6686
Week*Time of Day*Infloresence*Forbs in Flower	2	2	24.1663	1.0837	0.3384
Plant	17	17	6601.1964	34.8249	<.0001*

Table 24 ANOVA table for the mean value of 1-D in Simpson's Diversity Index for the visiting morphospecies. Calculated using the total visits for each seed mix and seeding rate combination from the months of June, July, August, and September. Includes the variables of seeding rate (rate), and the seed mix (mix).

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mix	1	1	0.00013196	0.0137	0.9080
Rate	2	2	0.00208967	0.1088	0.8975
Mix*Rate	2	2	0.00504526	0.2628	0.7718

Table 25 ANOVA table for the mean value of 1-D in Simpson's Diversity Index for the plants receiving visits. Calculated using the total visits for each seed mix and seeding rate combination from the months of June, July, August, and September. Includes the variables of seeding rate (rate), and the seed mix (mix).

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mix	1	1	0.00347166	0.2344	0.6341
Rate	2	2	0.01017607	0.3435	0.7138
Mix*Rate	2	2	0.00170933	0.0577	0.9441

Table 26 ANOVA table for the mean value of 1-D in Simpson's Diversity Index for the visiting morphospecies. Calculated using the total visits for each seed mix and seeding rate combination from the months of June, July, August, and September. Includes the variables of seeding rate (rate), the seed mix (mix), and the value of 1-D in Simpson's Diversity Index for the plants receiving visits.

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mix	1	1	0.00028237	0.0433	0.8376
Rate	2	2	0.00013177	0.0101	0.9900
Mix*Rate	2	2	0.00755487	0.5793	0.5710
Plant 1-D	1	1	0.06194720	9.5004	0.0068*

Table 27 ANOVA table for the mean coverage of *Agastache foeniculum* in the spring sown plots with the variables of seeding rate (rate) and the seed mix (mix).

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mix	1	1	0.23888229	12.6165	0.0005*
Rate	2	2	0.18970030	5.0095	0.0077*
Mix*Rate	2	2	0.10566637	2.7904	0.0644

Table 28 ANOVA table for the mean distance stretched during the greenhouse grown sod stretch test with the variables of seeding rate (rate), and the seed mix (mix).

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mix	1	1	0.2083333	0.3419	0.5642
Rate	2	2	1.0326667	0.8474	0.4410
Mix*Rate	2	2	0.8486667	0.6964	0.5082

Table 29 ANOVA table for the mean species richness at the time of transplant for the greenhouse grown sod with the variables of seeding rate (rate) and the seed mix (mix).

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mix	1	1	0.00255172	0.4435	0.5118
Rate	2	2	0.09828644	8.5411	0.0016*
Mix*Rate	2	2	0.01212043	1.0533	0.3644

Table 30 ANOVA table for the mean species richness at the end of the evaluation for the greenhouse grown sod with the variables of seeding rate (rate) and the seed mix (mix).

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mix	1	1	0.05216571	10.5809	0.0034*
Rate	2	2	0.00264833	0.2686	0.7667
Mix*Rate	2	2	0.00633739	0.6427	0.5347

Table 31 ANOVA table for the mean species richness of the greenhouse grown sod with the variables of the month of evaluation (month), seeding rate (rate), and the seed mix (mix).

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mix	1	1	0.0388962	7.2813	0.0096*
Rate	2	2	0.0408854	3.8268	0.0287*
Mix*Rate	2	2	0.0061028	0.5712	0.5686
Month	1	1	1.7191151	321.8137	<.0001*
Mix*Month	1	1	0.0158213	2.9617	0.0917
Rate*Month	2	2	0.0600494	5.6205	0.0064*
Mix*Rate*Month	2	2	0.0123550	1.1564	0.3232

Table 32 ANOVA table for the biomass of spontaneous vegetation occurring within the transplanted sod grown over plastic at the end of the evaluation period with the variables of seeding rate (rate) and the seed mix (mix).

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mix	1	1	62285.185	6.5582	0.0250*
Rate	1	1	994.456	0.1047	0.7518
Mix*Rate	1	1	143.640	0.0151	0.9042

Table 33 ANOVA table for the mean species richness of spontaneous vegetation occurring within the transplanted sod grown over plastic at the end of the evaluation period with the variables of seeding rate (rate) and the seed mix (mix).

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mix	1	1	0.00005317	0.0080	0.9301
Rate	1	1	0.01750109	2.6445	0.1299
Mix*Rate	1	1	0.00487088	0.7360	0.4077

Table 34 ANOVA table for the mean species richness of the sod grown over plastic at the time of transplant with the variables of seeding rate (rate) and the seed mix (mix).

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mix	1	1	7.5625000	4.1724	0.0637
Rate	1	1	0.0625000	0.0345	0.8558
Mix*Rate	1	1	5.0625000	2.7931	0.1205

Table 35 ANOVA table for the mean species richness of the transplanted sod grown over plastic at the end of the evaluation period with the variables of seeding rate (rate) and the seed mix (mix).

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mix	1	1	12.250000	6.0000	0.0306*
Rate	1	1	0.250000	0.1224	0.7325
Mix*Rate	1	1	4.000000	1.9592	0.1869

Table 36 ANOVA for the mean species richness of the transplanted sod grown over plastic with the variables of month of evaluation (month), seeding rate (rate), and the seed mix (mix).

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mix	1	1	19.531250	10.1351	0.0040*
Rate	1	1	0.281250	0.1459	0.7058
Mix*Rate	1	1	9.031250	4.6865	0.0406*
Month	1	1	1.531250	0.7946	0.3816
Mix*Month	1	1	0.281250	0.1459	0.7058
Rate*Month	1	1	0.031250	0.0162	0.8997
Mix*Rate*Month	1	1	0.031250	0.0162	0.8997