ABSTRACT

GRAGG, BENJAMIN RICHARD. Zoysiagrass (*Z. japonica*) Establishment Methods and Timings Evaluation and Comparison of Large-Scale Sprigging Equipment for Establishment of North Carolina Roadsides (Under the direction of Dr. Grady Miller).

Establishing uniform, perennial vegetation on a large area can be difficult to achieve, especially on a roadside setting with minimal inputs. Also, vegetation management on roadsides and around guardrails is time consuming and expensive for a Department of Transportation. These organizations desire a dense vegetation that has slow vertical growth and minimal weed invasion once established, and zoysiagrass (*Zoysia* spp.) is a suitable vegetation for this use. The first objective of this study is to evaluate various planting timings of seed and sprigs for establishing zoysiagrass on NC roadsides. 'Compadre' and 'Crowne' zoysiagrass (*Zoysia japonica* Steud.) plantings were made in fall 2017 and 2018 (September, October, November) and spring 2018 and 2019 (March, April, May) in Lenoir and Yadkin Counties, NC. Following tillage, Crowne was sprigged while Compadre was sprigged and seeded onto 2.4 x 3.7 m plots. During the second year, the seeded cultivar was changed to 'Zenith' (*Z. japonica* Steud.) because the lack of available Compadre seed. Data collection was initiated in summer of 2018 and continued to July 2020. Mean percentage of zoysiagrass cover was recorded individually for each establishment timing and method. In Yadkin, March and May seedings in year 1 achieved 95% and 98% coverage, respectively; whereas Compadre sprigging coverage was 67%, respectively, as of September 2018. In Lenoir, seed planted in November 2017 and March 2018 achieved 32% and 35% cover, respectively, whereas sprig plantings showed <6% coverage in September 2018. Zoysiagrass planted via seed was faster to establish with greater coverage for both location and all timings compared to sprigging. Late spring to early summer is typically suggested for seeding dates of warm-season grasses, which agrees with research findings.

However, after one calendar year, fall and spring seed plantings showed similar coverage. Although establishment and coverage from sprigging material was not rapid, it should be noted that zoysiagrass sprigs were able to show comparatively similar coverage to seed plantings after about 12-18 months.

A second objective of this study was to evaluate fall and spring zoysiagrass establishment using large-scale sprigging equipment on North Carolina roadsides. Additionally, a third objective was to evaluate the effects of cover materials on the establishment of zoysiagrass sprigs. Field research was initiated in the fall (October 2017 and 2018) and spring (May 2018 and 2019) in Lenoir and Rowan County, NC. Sprigging units consisted of an older, disk-driven sprigger that incorporated sprigs below the soil surface, a newer sprigging unit that leaves sprigs on the soil surface, and the new sprigger following by post sprig disking. 'Compadre' zoysiagrass (*Zoysia japonica* Steud.) sod rolls were utilized throughout this study and fed into respective spriggers to apply sprigs onto 18.3 m × 1.5 m whole plots. Cover materials of excelsior mat, coastal bermudagrass straw, and an uncovered control were applied as split plots. In fall plantings of year 1, the new sprigger, with and without disking resulted in the greatest coverage throughout this study; however, the old sprigger in Lenoir resulted in coverage that was not different from the new sprigger in Rowan. Both years of plantings in the spring and year 2 fall plantings were largely unsuccessful (≤15% coverage). Minimal differences among cover materials were present in both locations. Results suggest the limitation in large-scale sprigging equipment use for establishing zoysiagrass may be impacted more by limited available water than the equipment. Overall, results from this research suggest that zoysiagrass can be established on NC roadsides with minimal inputs. Additionally, this research suggest further research is needed on other methods of low-input establishment of zoysiagrass.

Zoysiagrass (*Z. japonica*) Establishment Methods and Timings Evaluation and Comparison of Large-Scale Sprigging Equipment for Establishment of North Carolina Roadsides

by
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DEDICATION

I would like to dedicate this thesis to my better half, Lara Nicole Phillips. You have continued to encourage and support me over the past two years. I would not be in the position I am today without you being in my life, and for that I am thankful.

BIOGRAPHY

Benjamin Richard Gragg was born on September 15, 1995 to Joseph Gragg and Kimberly Eagle (formerly Gragg) in Salisbury, North Carolina. Ben gained early experience in turfgrass management as a toddler and could be found riding on the lawn mower with his father every chance possible. Taking after his older brother Zack, Ben found passion in sports and grew up playing baseball and football. Whether it was playing wiffle-ball in the front yard, riding his dirt-bike or 4-wheeler, or working at a local golf course, Ben was always found outside.

In the spring of 2013, Benjamin graduated from Jesse C. Carson High School in China Grove, North Carolina and began pursuing his baseball dream by accepting a scholarship to play at Wingate University in the fall of 2013. Following shoulder injuries, he transferred to North Carolina State University in August of 2014 and began in the Animal Science program. Two years later, Ben elected to change majors and study Turfgrass Science at North Carolina State University. During his undergraduate career, he was employed at Lonnie Poole Golf Course in Raleigh, NC, during semesters, and participated in two summer internships at The Pearl Golf Links in Calabash, NC and Old Chatham Golf Club in Durham, NC. Additionally, Ben was awarded two years on the Dean’s List and was among the first to be recognized in the inaugural NC State Turfgrass Ambassador Leadership Program in 2018-19. In December of 2018, Ben completed the Bachelors of Science degree in Turfgrass Science and was granted the opportunity to continue his education.

In January of 2019, Benjamin began to work towards a Maters of Science degree in Turfgrass Management under the direction of Dr. Grady Miller. During the pursuit of his Master degree, Ben had the opportunity to speak at university field days and interact with some of the most highly respected turfgrass scientists. Upon completion of his degree, Benjamin intends to continue an active career in the turfgrass industry and is open to new opportunities.

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LITERATURE REVIEW

Zoysiagrass

Zoysiagrass (*Zoysia* spp. Willd.) is an introduced, perennial, sod-forming species that is well adapted for turf in the transitional and warm climatic regions in the United States. The genus *Zoysia* is indigenous to the coastal Pacific Rim and consists of 11 species (Anderson, 2000). In the United States, *Zoysia japonica* Steud. (previously Japanese or Korean Lawngrass) and *Zoysia matrella* (L.) Merr. (previously Manilagrass) are the two most commonly used zoysiagrass species and collectively referred to as zoysiagrass (Kimball et al., 2013; Patton, 2009). According to Sturkie (1941), 'Matrella' (FC 13521), was the first *Z. matrella* cultivar released in the late 1930s. Zoysiagrass was immediately popular in the southern United States in the 1940s because few well-adapted species for lawns were available (USGA Green Section, 1944). Forbes and Ferguson (1947, 1984) noted the special value of *Z. japonica* in the "crabgrass belt," an early euphemism for the transitional climatic zone. The transition zone extends through the central part of the United States and is historically known for being too cold in winter for warm-season species, and alternatively, too warm in the summer for cool-season species (Dunn and Diesburg, 2004). Winter injury to warm-season grasses may result in stand decline or death, as well as increased disease pressure during spring transition. Alternatively, high temperatures, high humidity, and reduced precipitation during summer causes cool-season grasses to decline, allowing crabgrass and other weeds to colonize (Beard, 1973; Forbes and Ferguson, 1947).

Soon after the release of Matrella, the improved *Z. japonica* cultivar 'Meyer', was released in 1951 (Hanson, 1965). Meyer quickly became the industry standard for zoysiagrass because of its superior cold tolerance. More than 70 years after its release, it is still the most utilized zoysiagrass in the transition zone (Patton et al., 2017). Although initially popular in the South, lack of *Z. matrella* plant material and improvements in bermudagrass (*Cynodon dactylon* L.), centipedegrass (*Eremochloa ohpiuroides*), and St. Augustinegrass (*Stenotaphrum secundatum*) slowed its utilization (Patton et al., 2017). The efforts of turfgrass breeders and scientists resulting in major improvements in biotic and abiotic stress tolerances have allowed the continued expansion of zoysiagrass use, particularly in the Midwest and throughout the transition zone (Patton et al., 2017). In the United States today, zoysiagrass in grown from Florida to Connecticut and extending westward along the Gulf Coast into Texas and Kansas (Duble, 1996; Patton, 2009). In North Carolina, while zoysiagrass is commonly utilized in home lawns, golf courses, and commercial landscapes, there is a growing interest in its use for low maintenance areas like parks, cemeteries, and roadsides.

Over the past 40 years, zoysiagrass use in home lawns had continued to increase throughout the transition zone due in part to its overall density, color, available textures, and reduced encroachment. Additionally, its superior cold tolerance compared to bermudagrass (Cynodon spp.) cultivars enables a broader environmental range for zoysiagrass utilization (Anderson et al., 2002). Cold tolerance varies within the *Zoysia* genus. *Z. japonica* is more cold tolerant than *Z. matrella*, and all other warm-season turfgrass species (Beard, 1973). Winter injury of zoysiagrass was first reported by Forbes and Ferguson (1947). In West Lafayette, IN, Patton and Reicher (2007) assessed winter injury of 35 zoysiagrass field plots, consisting of commercially available cultivars or experimental genotypes. They concluded *Z. japonica* genotypes had less winter injury than *Z. matrella* genotypes, which agrees with numerous other reports. ‘Chinese Common’, Meyer, and ‘Zenith’ (all *Z. japonica*) were the only commercially available cultivars to have less than 7% winter injury in both years (Patton and Reicher, 2007). Zoysiagrass rhizomes located under the soil surface provide additional cold tolerance compared to stoloniferous warm-season grasses as soil temperatures remain warmer and do not fluctuate as much during winter (DiPaola and Beard, 1992).

Additionally, Patton and Reicher (2007) evaluated the freeze tolerance of selected commercially used zoysiagrass genotypes with low, medium, and high winter injury. Plants were established in the greenhouse with supplemental lighting for 10 weeks, then cold acclimated for 4 weeks (8/2 °C day/night temperatures) with a 10-hr photoperiod of 300 μmol m^{-2} s^{-1} photosynthetically active radiation. They concluded the LT_{50} (temperature at which no regrowth occurs in 50% of the plants) for zoysiagrass ranged from -8.4 to -11.5 °C. Cultivars Meyer and Zenith had superior freeze tolerance, resulting in at least 50% regrowth when subjected to soil temperatures as low as -11.5 °C (11.3 °F) (Patton and Reicher, 2007). Their experimental control 'Midlawn' bermudagrass had an LT_{50} of -8.6 °C, which is similar to reports of several bermudagrass cultivars ranging from -4.8 to -8.4 °C (Anderson et al., 2002).

Zoysiagrass Establishment

Despite early recognition of its benefits, expanded use of zoysiagrass has been limited primarily due to the high cost of vegetative establishment, limited availability of seeded cultivars, and complications during establishment (Samudio, 1996; Patton et al., 2007). Zoysiagrass sod, regardless of variety, is generally more expensive than other warm-season grasses because of longer production time (Engelke, 1988). The prices for zoysiagrass sod listed in the NC sod producers report suggest this is generally true (Miller, 2020). Vegetative plantings as sod, sprigs, or plugs remain the common zoysiagrass establishment methods because of limited availability of seeded cultivars. The advantage of sod is the instantaneous ground cover it provides; however, it can desiccate rapidly after planting without timely watering due to compromised root systems (Turgeon, 2012).

Potential desiccation combined with the high cost of zoysiagrass sod results in more growers utilizing sprigs or plugs to establish a new stand. Sprigs are individual stolons and rhizomes containing several nodes from which new plants may develop. Typically, sprigs have some roots or leaves attached and are relatively free of soil (Turgeon, 2012). Plugs are small cylindrical- or blocked-shaped sections of turf extracted from the field or strips of sod and may have up to several inches of soil attached (Turgeon, 2012). Sprigs are commonly broadcast uniformly across the respective area while plugs are transplanted into the soil at intermittent intervals. Once applied, sprigs must be incorporated into the soil with a disk or topdressed and rolled to ensure sprig-to-soil contact (McCarty, 2011). The major benefit of establishing a sward via sprigs or plugs is that a fraction of the plant material is needed compared to sodding, therefore, the initial cost is significantly reduced. The downfall is the time to complete zoysiagrass cover is greatly increased and may require additional maintenance inputs or cultural practices.

Forbes and Ferguson (1948) experienced early troubles during seed establishment, stating "seed dormancy factors resulted in extremely poor germination". Historically, seeded zoysiagrass has had limited use because of low germination rates, minimal seed availability, and poor turf quality found in Chinese Common and 'Korean Common' zoysiagrass (Samudio, 1996; Yeam et al., 1981). Zoysiagrass seed was not commercially available in the United States until 1993 when two *Z. japonica* cultivars, Zenith and 'Compadre' (formerly 'Companion'), were developed (Patton et al., 2017). Those two, along with 'Cathy' (*Z. japonica*), remain the only seed varieties commercially available today. Their "availability" remains an issue; Compadre seed was available for purchase in 2017, but failures during seed production prevented this in 2018. Today, all commercially available zoysiagrass seeds are chemically scarified to improve germination rates and the feasibility of using seed on a large scale (Patton et al., 2006). Although it is not utilized nearly as much as vegetative propagation, establishment of zoysiagrass from seed has tremendous potential because it provides the same benefits at a fraction of the cost of (Patton et al., 2006). In 2006, Patton et al. reported the cost to established one acre of fairway with zoysiagrass to be $3,000 using sprigging, $5,000 using strip sodding and $16,000 using solid sodding. Meanwhile, the cost to establish the same area of zoysiagrass by seed was approximately $900.

Concerns about Zoysiagrass

The disadvantages of zoysiagrass are few, but slow establishment and growth rate are the main concerns, especially compared with bermudagrasses (*Cynodon* spp.) (Busey and Myers, 1979). Poor recuperative potential and delayed establishment are a direct result of slow growth rates. This may lead to increases in initial maintenance costs, weed pressure, soil erosion, plant desiccation, and an overall reduction of associated aesthetics. Patton et al. (2007b) determined the establishment rate of 35 zoysiagrass genotypes and found that *Z. japonica* genotypes were able to produce more coverage and had a faster establishment rate than *Z. matrella* by proportioning more dry matter to their stems instead of their leaves.

When establishing zoysiagrass via seed, seeding rates and date are important considerations. In West Lafayette, IN, Patton et al. (2004b) evaluated the effect of seeding rate of Zenith zoysiagrass establishment in June 2001 and 2002. The seeding rates were 24, 48, 98, 146, 195, and 293 kg ha^{-1}. Plots were irrigated and covered with germination blankets to encourage establishment, along with 49 kg ha^{-1} month^{-1} N applications. There was no improvement in zoysiagrass coverage by seeding beyond the 98 kg ha^{-1} rate when evaluated 42 days after seeding (DAS) (Patton et al., 2004b). The authors also mentioned if rapid establishment is required, a 24 kg ha^{-1} seeding rate should not be used as it produced significantly less coverage than 48 kg ha^{-1} until 70 DAS. Patton et al. (2004a) also conducted a field study renovating golf course fairways to evaluate the effect of seeding rate and herbicide safety on zoysiagrass establishment. Zoysiagrass coverage, when established in Richmond, KY., Camby, IN., and Evansville, IN., was highest in plots where weeds were effectively controlled and zoysiagrass was seeded at 98 kg ha^{-1} resulting in 3%, 4%, 11% more coverage than 49 kg ha^{-1}, respectively (Patton et al. 2004a). However, the authors pointed out the $2,200 ha^{-1} cost of increasing the seeding rate from 49 to 98 kg ha^{-1} with marginal improvements in zoysiagrass coverage may not be worth the expense.

In the study previously mentioned, Patton et al. (2004b) also evaluated the effect of seeding date and nitrogen fertility on zoysiagrass establishment in West Lafayette, IN and Lexington, KY. Plots were seeded in 2001 and 2002 at 49 kg ha^{-1} every 15 days between 1 June and 1 September 1 (± 2 d). In Indiana, plots received 49 kg ha^{-1} N at seeding and every 15 DAS while Kentucky received 49 kg ha^{-1} N at seeding and applied every 15 or 30 DAS with the final application on 30 September. Zoysiagrass seeded before 1 July in Indiana, 1 July 2000 and 15 June 2001 in Kentucky produced the highest coverage by first frost in October (Patton et al., 2004b). Their results also indicated that increasing monthly N fertilization from 49 to 98 kg ha^{-1} does not improve Zenith zoysiagrass establishment by seed.

Current literature primarily focuses on cultural practices to enhance the establishment of zoysiagrass sprigs. However, there is a lack of relevant information regarding the effect of sprigging rate. Fertility applied during establishment is often used to enhance the growth and establishment rate of zoysiagrass sprigs. 'Meyer' zoysiagrass was subjected to nitrogen rates of 12.5, 25, 37.5, and 50 kg ha^{-1} $month^{-1}$ during establishment of sprigs at two location in Arkansas (Richardson and Boyd, 2001). They concluded that high levels of N fertilizer (>37.5 kg ha^{-1} $month^{-1}$) had little or no more effect on establishment compared with low levels (<25 kg ha^{-1} $month^{-1}$). In Jackson Springs, NC, zoysiagrass sprigs were established using two fertilization regimes, beginning at the initiation of the trial, to apply a seasonal total N rate of 250.0 kg ha^{-1} for each plot (Cooper et al., 2013). The first N regimen consisted of nine weekly applications of 25.0 kg N ha^{-1}. The second N regimen began with three weekly applications of 12.5 kg N ha^{-1}, followed by three weekly applications of 25.0 kg N ha^{-1}, followed by three weekly applications of 37.5 kg N ha^{-1}. Cooper et al. (2013) determined sprig establishment rates of the eight (year 1) and nine (year 2) commercially available zoysiagrass cultivars that were tested did not vary significantly in response to the fertilization regimes. Most reports agree that some N fertilizer is beneficial for zoysiagrass establishment, but application should be kept to a minimum and not exceed 49 kg ha^{-1} $month^{-1}$ (Patton et al., 2004b).

Cover technologies, mulches, and erosion control blankets are other cultural practices that are often used during turf establishment. A field study conducted in Fayetteville, AR evaluated the effects of various permanent and temporary seed cover technologies on the establishment of Zenith zoysiagrass seeded at 98 kg ha^{-1} (Patton et al., 2010). There was a total of 10 different covers/ mulches tested, along with a non-cover control. Covers consisted of products like mats made with polyethylene, excelsior aspen wood fiber, thermally refined wood, fiber mesh, and thermal blankets consisting of needle-punch, nonwoven polypropylene. Mulches included wheat straw applied at 3096 kg ha^{-1} (80 lbs. 1000 ft^{-2}). The thermal blanket and non-covered control were the only covers to show significantly less zoysiagrass coverage than all others in 2007; whereas in 2008, straw mulch has significantly less turfgrass than all other covers (Patton et al., 2010). Boyd et al. (2003) conducted zoysiagrass propagation studies in Fayetteville and Little Rock, AR were treatments consisted of traditional sprigging at 70 m^3 ha^{-1}, with and without an additional 1 cm of native soil topdressing, and a ZNET (Winrock Grass Farms, Little Rock, Ark.) treatment with the same topdressing. The ZNET method utilized two layers of biodegradable netting with zoysiagrass sprigs intertwined within the netting; the netting is rolled onto the site, similar to sod. In general, the ZNET planting method outperformed the traditional sprigging techniques, but only by < 10%, which is not economically significant in a field situation (Boyd et al., 2003).

North Carolina Roadsides

Turfgrass contributes significantly to our physical environment. Established turfgrass stands control wind and water erosion of soil and are essential in eliminating dust and mud problems. Turfgrasses can also reduce glare, noise, air pollution, and heat buildup. Roadside turf stands provide all those contributions, as well as provide highway safety by serving as a stabilized zone for emergency stopping of vehicles (Beard, 1973). In the United Stated, there are over 17 million acres of roadsides that need regular vegetation management (Martin et al., 2017). Roadside vegetation management is an arduous endeavor that balances providing safe travel routes with preserving road system infrastructure in an environmentally responsible manner (NCHRP, 2005). Poorly managed vegetation can have adverse impacts on roadways due to increased risk to traffic and premature deterioration of the road system infrastructure (Martin et al., 2017). Excessive vegetation has the ability to trap debris and impede water drainage, which can adversely affect driving surfaces. Mowed roadside turf stands enhance line-of-sight visibility and view of signs and animal hazards, which are vital factors for operators of fast-moving vehicles (Beard and Green, 1994).

The North Carolina Department of Transportation (NCDOT) has one of the largest state-maintained highways systems in the nation with 80,000 centerline miles: 15,000 miles of primary highways (Interstates, US and NC routes) and 65,000 miles of secondary roads (NCDOT, 2020). This translates to over 660,000 acres of turfgrass and over 1,000 miles of median and guardrails the NCDOT Roadside Environmental Unit (REU) must maintain. Guardrails are installed to reduce the amount of damage and severity of personal injuries during an accident, however, as foliage height increases around them, vision impairment of motorist becomes a major concern (Delaware DOT, 2009). The inherent design of guardrails has led to a combination of chemical and mechanical weed control strategies to control vegetation around them. These strategies have proven to be time consuming and expensive to implement. String trimming (weed-eating) with manual labor is a common practice used to control the excessive vegetation, but it is costly (\$164 and \$702 km^{-1} in North Carolina and Washington, respectively), and it poses high worker safety concerns (NCDOT, 2016; Washington DOT, 2003). Due to the varying climatic and edaphic conditions in NC, roadside vegetation managers are presented with a wide range of pest and turfgrass management scenarios that pose substantial ecological and economic challenges to provide safe travel routes for motorists (Gannon et al., 2016). Additionally, public awareness of environmental impacts associated with vegetation management has led to the development of Integrated Roadside Vegetation Management

Programs (IRVMPs) across the U.S. These programs work to combine traditional vegetation management approaches such as mowing and pesticide application, with eco-regional approaches (Martin et al., 2017).

The NCDOT is structured into fourteen divisions with each of them consisting of roughly seven counties. Across the state, fescues (*Festuca* spp.) make up the greatest percentage of turfgrass type on all road systems, followed by centipedegrass (*Eremochloa ohpiuroides*). On interstates and secondary systems, bahiagrass (*Paspalum notatum*) is more common than bermudagrass; however, on primary systems, bermudagrass is more common than bahiagrass (Martin et al., 2017). In one complete calendar year, on average, the NCDOT requires 4-5 mowing cycles on interstates, 3-5 cycles on primary roads, and 4-5 cycles on secondary roads. Temperature and moisture are the major climatic factors determining species adaptation and selection. Therefore, dominant turfgrass species and the number of mowing cycles varies greatly across NCDOT divisions. The NCDOT currently has specific seed and mixture requirements for turfgrass establishment under guardrails and along roadsides, which varies with county location (east or west) (NCDOT, 2019a). For turfgrass establishment under guardrails, centipedegrass seed is used for eastern NC while hard fescue (various *Festuca* spp.) and Kentucky bluegrass (*Poa pratensis*) seeds are used in western NC (NCDOT, 2019a). In other roadway areas in eastern, NC, a seed mixture of tall fescue, centipedegrass, and bermudagrass (hulled) is utilized between 1 March – 31 August; for the remainder of the year, the same mix is used but bermudagrass seed is unhulled (NCDOT, 2019b). Those requirements also mention that bahiagrass may be substituted for either centipede or bermudagrass. In western, NC, a seed mix of Kentucky bluegrass, hard fescue, and rye grain (*Secale cereal*) is utilized between 1 August – 1 June for shoulder and median grass establishment; rye grain is replaced by German millet

(*Setaria italica*) or Browntop millet (*Urochloa ramosa*) during 1 May – 1 September (NCDOT, 2019c).

Zoysiagrass for NC Roadsides

To date, little research has been performed regarding roadside establishment and management of zoysiagrass in North Carolina. Field trials were conducted by Gannon et al. (2016), in coordination with the NCDOT, to evaluate the effect of Zenith zoysiagrass seeding rates and seeding times on roadside establishment success along guardrails in Lee and Orange County, NC. During March, April, and May of 2013 and 2014, Zenith zoysiagrass was seeded at 24.7 and 37.1 kg pure live seed (PLS) ha^{-1} (22 and 33 lb PLS A^{-1}), which was done with a tractor-mounted Tye® drill (10 shoots on 8 in spacing) to a 1.27 cm (0.5 inch) depth; subsamples of seed were collected at all timings and confirmed viable. Prior to seeding in 2013, plots were mown to 7.62 cm (3 in) height to improve seed planting. In 2014, glyphosate was applied at 1.6 kg ha^{-1} (1.4 lb A^{-1}), 1 to 3 days prior to seeding because no uniform emergence was observed in 2013. Across all evaluated variables, < 5% seed emergence was observed throughout the research period (72 weeks after initial seeding) (Gannon et al., 2016). The authors attributed this to a combination of non-ideal soil conditions, inadequate moisture inputs, and existing plant competition. However, there is no surprise zoysiagrass seed did not germinate when it was drilled to 1.27 cm depth – especially when drilled into existing 3-inch vegetation – since zoysiagrass seed requires light to germinate and should not be buried deeper than 0.64 cm (0.25 inch) (Forbes and Ferguson, 1948). Gannon et al. (2016) concluded results from this research do not warrant recommending zoysiagrass seeding on NC roadsides, but the potential for reduce long-term management coupled with zoysiagrass seeding's significantly lower fiscal requirements compared to sodding suggest additional research should be conducted to re-examine seeding as well as sprigging at various timings.

A separate field experiment in the Gannon et al. (2016) report (later published by Jefferies et al. 2017) evaluated the effects of cultivar, establishment timing, and soil preparation technique on zoysiagrass sod establishment and spread along guardrails across three counties in NC (Chatham, Lee, and Yadkin). 'El Toro' (*Z. japonica*) and 'Zeon' (*Z. matrella*) were established for two years in December, March, April, and May using the following soil preparation techniques: stripping native vegetation with a sod cutter, tillage alone, and tillage + bed preparation prior to planting. The authors arbitrarily set successful sod establishment at ≥60% cover. Year 1 plantings of El Toro successfully established at all timings in Chatham, while Lee (Dec., Mar., and May) and Yadkin (April and May) plantings were unsuccessful at 125 weeks after initial establishment (WAIE) (Jefferies et al., 2017). To note, the successful establishment previously mentioned ranged from 62% to 82% cover. The authors went on to mention that Zeon followed similar results at 90 and 125 WAIE, with 63 to 77%, 16 to 61%, and 18 to 38% cover following April and May plantings at Chatham, Lee, and Yadkin, respectively. Overall plantings in year 2 resulted is poor cover at 125 WAIE, with only four of the 24 location-cultivar-timing combinations providing successful establishment (Jefferies et al., 2017). In evaluating main effects of soil preparation techniques, Jefferies et al. (2017) discovered that tillage + bed preparation provided the best sod establishment in year 1, but tillage alone also provided successful establishment at 90 and 125 WAIE and resulted in similar establishment in year 2. It was concluded that December and March plantings provided the most consistent results when successful establishment occurred. Moreover, the authors explained that March is recommended because it allows vegetation managers to avoid laying sod that will be subject to extreme cold temperatures common in NC from December to February and improve establishment success potential (Jefferies et al., 2017).

For roadsides, the most desirable traits are rapid establishment and recuperative rates, tolerance to a variety of soil and nutrient situations, freeze and drought tolerance, and a dense canopy to suppress weed encroachment. Characteristics pertinent to zoysiagrass establishment on roadsides and along guardrails include a low, prostrate growth habit, as well as favorable cold, drought, salt, and wear tolerances (Patton, 2009). Once established, zoysiagrass creates a dense and low-growing turf that spreads by an intergradation of thick stolons and rhizomes that form a very tight, tough, prostrate growing turf (Beard, 1973). The tight growth habit and high shoot density of healthy zoysiagrass swards allow relatively few weeds to colonize (Patton et al., 2017). The scarcity of weeds has been documented by several authors (Forbs and Ferguson, 1947; Diesburg, 2001; Fry et al., 2008), and based on personal observation, zoysiagrass swards typically have fewer weeds present during the growing season than turf expanse that consist primarily with other species in NC (i.e., bermudagrass and tall fescue). The most problematic weeds are winter annuals that are able to colonize during winter dormancy of zoysiagrass (Patton et al., 2017).

Zoysiagrass discolors with the advent of 10 to 12.8 °C temperatures and remains in a state of dormancy throughout the winter period (Beard, 1973). Throughout the transition zone, zoysiagrass enters dormancy typically in November and resumes growth in April (Dunn and Diesburg, 2004). This can translate to lower maintenance cost for government agencies on roadsides as dormant turf can provide multiple months where minimal management is required. Additionally, the improved cold tolerance, along with the ability of zoysiagrass to survive soil temperatures as low as -11.5 °C (11.3 °F) (Patton and Reicher, 2007), provides a wider range of establishment across the varying climatic conditions found in NC.

Earlier, it was mentioned how the slow growth rate of zoysiagrass was its biggest disadvantage, although that may not always be true. Compared with bermudagrass, zoysiagrass grows more slowly and is less likely to encroach onto or over sideways and curbs; it would also requires less trimming around signs and safety structures on a roadside setting (Busey and Myers, 1979). A reduced clipping yield compared to bermudagrass is another strength of zoysiagrasses slow growth rate (Trappe et al., 2011b). On roadside use, this can translate into less mowing and string trimming requirements, and lower clipping yields are less likely to prevent proper storm water management systems. Additionally, this provides increased worker safety and less fossil fuel consumption for government agencies. Directly associated with its slow growth rate is lower nutritional requirements for zoysiagrass (Patton et al., 2017). Fertilizer recommendations for zoysiagrass are much lower, typically range from 73 to 146 kg N ha^{-1} yr^{-1}, when compared to common and hybrid bermudagrasses which require around 195 to 400 kg N ha^{-1} yr^{-1}, if not more (Turgeon, 2012). In relation to roadsides, low nutrient requirements are an important aspect as roadside turfs receive minimal fertilization once established.

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CHAPTER 1

Evaluation of Zoysiagrass (*Z. japonica*) Establishment Methods and Timings on North Carolina Roadsides

Abstract

Vegetation management around roadsides and guardrails is time consuming and expensive for a Department of Transportation. These organizations desire a dense vegetation that has slow vertical growth and minimal weed invasion once established, and Zoysiagrass (*Zoysia* spp.) is a suitable vegetation for this use. The objective of this study was to evaluate planting timings and methods for establishing zoysiagrass on NC roadsides. ‘Compadre’ and ‘Crowne’ zoysiagrass (*Zoysia japonica* Steud.) plantings were made in fall 2017 and 2018 (September, October, November) and spring 2018 and 2019 (March, April, May) in Lenoir and Yadkin Counties, NC. Following tillage, Crowne was sprigged while Compadre was sprigged and seeded onto 2.4 x 3.7 m plots. During the second year, the seeded cultivar was changed to ‘Zenith’ (*Z. japonica* Steud.) due to Compadre seed scarcity. Data collection was initiated in summer of 2018 and continued to July 2020. Mean percentage of zoysiagrass cover was recorded individually for each establishment timing and method. In Yadkin, March and May seedings in year 1 achieved 95% and 98% coverage, respectively; whereas Compadre sprigging coverage was 67%, respectively, as of September 2018. In Lenoir, seed planted in November 2017 and March 2018 achieved 32% and 35% cover, respectively, whereas sprig plantings showed <6% coverage in September 2018. Zoysiagrass planted via seed was faster to establish with greater

coverage for both location and all timings compared to sprigging. Results from this research suggest that zoysiagrass can be established on NC roadsides with minimal inputs.

Introduction

Established turfgrass stands control wind and water erosion of soil and are essential in eliminating dust and mud problems. Turfgrasses can also reduce glare, noise, air pollution, and heat buildup. Roadside turf stands provide all those contributions, as well as provide highway safety by serving as a stabilized zone for emergency stopping of vehicles (Beard, 1973). The North Carolina Department of Transportation (NCDOT) has one of the largest state-maintained highways systems in the nation with 80,000 centerline miles: 15,000 miles of primary highways (Interstates, US, and NC routes) and 65,000 miles of secondary roads (NCDOT, 2020). This translates to over 660,000 acres of turfgrass and over 1,000 miles of median and guardrails the NCDOT Roadside Environmental Unit (REU) must maintain. The inherent design of guardrails has led to the use of a combination of chemical and mechanical weed control strategies to control vegetation that have proven to be time consuming and expensive to implement. To date, little research has been performed regarding roadside establishment and management of zoysiagrass in North Carolina.

Zoysiagrass (*Zoysia* spp. Willd.) is an introduced, perennial, sod-forming species in the United States that is well adapted in the transitional and warm climatic regions. Zoysiagrass was immediately popular in the southern United States in the 1940s because few well-adapted turfgrass species for lawns were available (USGA Green Section, 1944). Forbes and Ferguson (1947, 1984) noted the special value of *Zoysia japonica* Steud. in the “crabgrass belt,” an early euphemism for the transitional climatic zone. Cold winters create issues for warm-season grasses within the transition zone while hot, humid summers increase stress on cool-season grasses. Over the past 40 years throughout the transition zones, zoysiagrass use in home lawns has continued to increase due in part to its overall density, color, available textures, and reduced encroachment.

Also, its superior cold tolerance compared to bermudagrass (*Cynodon* spp.) cultivars enables a broader environmental range for zoysiagrass utilization (Anderson et al., 2002). Zoysiagrass is also more tolerant to shaded environments, while bermudagrass is the least shade tolerant of all warm-season grasses (Emmons, 1995).

Most cultivars of zoysiagrass are established vegetatively (e.g. sod, sprigs, or plugs); however, the high cost of sod has led to an increases interest in sprig utilization to establish new stands. Although it is not utilized nearly as much as vegetative propagation, Patton et al. (2006) explains how seeded zoysiagrass has tremendous potential because it can be planted at a fraction of the cost of zoysiagrass sod. The cost to establish zoysiagrass on one acre of fairway via sprigging or sodding was found to be 3 to 18 times more expensive than the cost of establishing seed (Patton et al., 2006). The main downside to seeding zoysiagrass is the limited germplasm available; 'Compadre' and 'Zenith' (both *Zoysia japonica*) are commercially available, along with 'Cathy' (*Z. japonica*) although it is a very low quality zoysiagrass. The disadvantages of zoysiagrass are few, but slow establishment and growth rate are common concerns. This may lead to increases in initial maintenance cost, weed pressure, soil erosion, plant desiccation, and an overall reduction of associated aesthetics. Therefore, planting dates and materials are important considerations. Current literature primarily focuses on cultural practices to enhance the establishment of zoysiagrass seed and sprigs, however, there is a lack of relevant information regarding the effect of planting date and material for low-input establishment of zoysiagrass.

Patton et al. (2004) evaluated a range of seeding rate (24 to 293 kg ha^{-1}) for 'Zenith' zoysiagrass established in June and found no improvements in zoysiagrass coverage with rates greater than 98 kg ha^{-1} when evaluated 42 days after seeding (DAS). In a separate part of that study, Patton et al. (2004) evaluated the effect of seeding date and nitrogen fertility on zoysiagrass establishment in Indiana and Kentucky. Plots were seeded at 49 kg ha^{-1} every 15 days between 1 June and 1 September; irrigation was applied as needed to promote establishment. Indiana plots received 49 kg ha^{-1} N at seeding and every 15 DAS while Kentucky received 49 kg ha^{-1} N at seeding and applied every 15 or 30 DAS with the final application on 30 September. Zoysiagrass seeded before 1 July in Indiana (92 – 100% coverage), 1 July 2000 (91 – 96%) and 15 June 2001 (100%) in Kentucky produced the highest coverage by the first frost in October (Patton et al., 2004). Authors acknowledged seeding dates before June 1 may have merit, but were not evaluated.

For roadsides, the most desirable turfgrass traits are rapid establishment and recuperative rates, tolerance to a variety of soil and nutrient situations, freeze and drought tolerance, and a dense canopy to suppress weed encroachment. Characteristics pertinent to zoysiagrass establishment on roadsides and along guardrails include a low, prostrate growth habit, as well as favorable cold, drought, salt, and wear tolerances (Patton, 2009). Once established, zoysiagrass creates a dense and low-growing turf that spreads by an intergradation of thick stolons and rhizomes that form a very tight, tough, prostrate growing turf (Beard, 1973). The tight growth habit and high shoot density of healthy zoysiagrass swards allow relatively few weeds to colonize (Patton et al., 2017). Jefferies et al. (2017) found that zoysiagrass sod strips can be successfully established (<60% coverage) along guardrails in NC and that December and March planting months were most effective when successful establishment occurred. The authors went on to mention that additional vegetative planting methods should be explored to reduce installation cost and minimize sod desiccation as periods for successful sod establishment on roadsides are comparably smaller than other turfgrass systems (Jefferies et al., 2017). Additionally, Gannon et al. (2016) observed < 5% ‘Zenith’ zoysiagrass seed emergence after 72 weeks regardless of seeding rate (24.7 and 37.1 kg pure live seed ha^{-1}) and planting date (March, April, or May). Gannon et al. (2016) concluded that zoysiagrass seeding on NC roadside was not warranted. However, the seed planted by Gannon et al. (2016) was drilled to a 1.27 cm (0.5 in) depth, which likely prevented emergence as zoysiagrass seed requires light to germinate. Forbes and Ferguson (1948) recommended planting depths of zoysiagrass seed to be ≤0.64 cm (0.25 in). The potential to reduce long-term management inputs coupled with zoysiagrass seeding's significantly lower establishment cost than sodding suggests additional research should be conducted (Gannon et al., 2016). In efforts to reduce initial and long-term maintenance cost while also increasing worker safety due to lower maintenance requirements, the objective of this research was to evaluate various planting timings of seed and sprigs for establishing zoysiagrass on NC roadsides.

Materials and Methods

Field research was initiated in the fall 2017 (September) and spring 2018 (March) (year 1) and repeated the following fall 2018 (September) and spring 2019 (March) (year 2) on North Carolina (NC) roadsides. Two locations were selected to represent the varying climatic and edaphic conditions present in NC. Lenoir County (35°18'08.6" N, 77°48'58.2" W) in the coastal plains region (USDA zone 8a) was chosen as an eastern site. Yadkin County (36°06'57.0" N, 80°46'21.8" W; and 36°06'43.2" N, 80°34'10.1" W) in the piedmont region (USDA zone 7a) was chosen as a western site. An additional site in Yadkin County was required during year 2 because of space constraints. Soil textural classifications of these sites are detailed in Table 1. Zoysiagrass (*Z. japonica*) planting material evaluated at both locations included 'Compadre' and 'Crowne' sprigs planted at of 13 m^3 ha^{-1}, and 'Compadre' seeded at 98 kg pure live seed (PLS) ha^{-1}. In year 2, 'Zenith' zoysiagrass (*Z. japonica*) seed was substituted and planted at the same rate because 'Compadre' seed was not commercially available. Planting materials were arranged in a randomized complete block design with three replications and plots measured 2.4 m × 3.7 m. During both years, three fall (September, October, November) and three spring (March, April, May) monthly plantings were evaluated (Table 2). No irrigation was applied throughout this research.

The treatment selection for zoysiagrass planting materials were made on the premises of a few things. The NCDOT has observed favorable sod establishment of Crowne under roadside conditions – promoting its selection. Compadre was chosen because it is commercially available as vegetative material and seed. Additionally, the seed treatment was selected because seed is less likely to desiccate compared to vegetative material. If no water is present at the time of planting seed with not perish, however, is must have some moisture present. Therefore, Compadre seed was also included. For the selection of planting months, spring is typically suggested for planting warm-season turfgrass, while the fall planting months were selected based on the lower water demand during that time of establishment.

Percent zoysiagrass cover was visually estimated monthly during the growing season (June – September). Percent cover ratings were on a 0 to 100% scale with 0 = no zoysiagrass cover and 100 = full zoysiagrass coverage (Figure 1). In figure 1, you will notice the visual representation of 0% cover still has vegetation within the respective plot area. Shortly after each monthly planting, volunteer vegetation would occupy the majority of the plots throughout this study. This is particularly true in Yadkin County and for the spring plantings overall. Data collection began in August 2018 for year 1 and August 2019 for year 2. Data of all monthly plantings within each year were recorded during all rating events.

A month prior to study initiation, the NC Department of Transportation (NCDOT) applied glyphosate (3.8 kg ai ha^{-1}) as a burn down, followed by tillage to approximately 15-cm depth to control pre-existing vegetation at each site. Perennial grasses were present at the site that warranted the higher rate (personal communication, Kevin Clemmer – NCDOT Roadside Vegetation Management Supervisor). Sprigs were made from sod removed from established plots at North Carolina State University's Lake Wheeler Turf Field laboratory, in Raleigh, NC. Approximately 24 hours before planting, sod measuring 1.0 m × 0.46 m × 0.02 m was harvested, mechanically shredded (Model AZ-7H, Shred Pax Corporation, Wood Dale, IL), bagged in cotton, and placed in a temperature controlled room (22 °C). At the test site, the respective area was lightly disked (Compact Disc Model: 14-10-CD-YK, King Kutter Inc., Winfield, AL) to cultivate the soil and remove existing vegetation before planting. Sprigs were broadcast by hand at a rate of 13 m^3 ha^{-1} and pressed into the soil with vertical coulter blades. Pre-weighed amounts of seed were broadcast by hand at 98 kg pure live seed (PLS) ha^{-1}. A rolling cultipacker (Model: KP-48-ATV, King Kutter Inc., Winfield, AL) was pulled across the entire planted area behind a utility vehicle (Model: X900, Kubota Tractor Corporation, Grapevine, TX) to ensure soil contact with seeds and sprigs. Experimental units received no supplemental irrigation beyond natural rainfall.

Beginning one month after May plantings, sites were clipped with a rotary mowers (Models: 74201 and 30284, The Toro Company, Bloomington, MN) between a 6.35 – 7.62 cm (2.5 – 3 in) height of cut on a monthly basis during the growing season. Various applications of a granular fertilizer (25% N – 5% P_2O_5 – 10% K_2O) were made throughout the trial, but never totaling more than 97.6 kg N ha^{-1} per calendar year (Table 3). In February 2019, oxadiazon [2-tert-butyl-4-(2,4 dichloro-5-isopropoxyphenyl)-2-1,3,4-oxadiazoline-5-one] (Oxadiazon 2G, Quali-Pro) was applied at 3.3 kg ha^{-1} to all year 1 plantings and fall plantings in year 2. In February 2020, oxadiazon was applied at the same rate as year 1 to all east plantings but was omitted from west plantings because of low summer annual weed pressure. Meteorological data was acquired from the closest weather station provided by the North Carolina Climate Retrieval and Observation Network of the Southeast (CRONOS, 2014). East weather data was gathered from Cunningham Research Station (35°17'49.9" N, 77°34'26.4" W), approximately 22 km from the Lenoir plots. West data was collected from Smith-Reynolds Airport (36°08'16.7" N, 80°13'34.8" W), approximately 48 and 30 km from both sites in Yadkin. Beginning 1 September through 31 August, during both years, weekly averages of maximum and minimum air temperature (°C), and cumulative weekly precipitation (cm) were collected from both stations (Figures 2 – 5).

This study analyzed planting months and material across two location in NC over two years. Lenoir and Yadkin County were selectively chosen to represent general climatic and edaphic conditions present in the coastal plains and piedmont regions of NC, therefore, location was a fixed effects. Cover data were subjected to analysis of variance using the PROC GLIMMIX procedure in the Statistical Analysis System software (version 9.4; SAS Inst. Inc., Cary, NC) to determine treatment effects and interactions. Significant year and location interaction occurred, therefore, data were sorted by year and location and presented separately (Table 4). Identified significant main effects and interactions were sorted and analyzed accordingly using least significant difference with a probability level of 0.05. Monthly progress in turfgrass establishment during the growing season (June – September) of multiple years, are presented as monthly means of percent zoysiagrass cover.

Results and Discussion

Environmental Influences

Significant year and location interactions occurred throughout data collection, as research locations were selected to represent the varying climatic and edaphic conditions present across NC. With no supplemental irrigation being applied, differences in precipitation patterns and amounts between years was the most likely cause for yearly interactions. During year 1, Lenoir County received a total of 136.3 cm of rainfall while 130 cm of rain fell during year 2 (Figure 2). In Yadkin County, 109.2 cm of precipitation fell during year 1 while a total of 142.5 cm of rain fell during year 2 (Figure 3). Additionally, both locations experienced cooler temperatures in the winter of 2017-18 compared to 2018-19. Higher spring temperatures occurred earlier in 2019 than in 2018. (Figures 2 and 3). Table 1 described the soil differences between Lenoir and Yadkin County, NC which contributed to location interactions, along with annual differences in precipitation. Like the majority of eastern NC soils, the research location in Lenoir County is dominated by sand-sized particles ($\geq$ 70%). Sand particles are relatively large, but have a low specific surface area, low water-holding capacity, and contribute very little to plant nutrition (Brady and Weil, 2010). In contrast, heavier soils are found in Yadkin County, NC, and contain at least 15% clay sized particles. Clay particles are very small and have a large specific surface area. Clay particles adsorb a great deal of water, with clay aggregates generating a broad range of pore sizes and is a more effective buffer between rainfall events. (Turgeon, 2012). This lead to greater overall zoysiagrass coverage in Yadkin County compared to Lenoir County during both years.

Yadkin County, NC

Analysis of variance determined significant planting month × planting material interactions on zoysiagrass cover estimates in every monthly rating during both years in Yadkin County, NC. This first initial rating in August 2018 occurred 45 and 19 weeks after planting (WAP) in September and March of year 1, respectively. Seed planted in March, April, May, and November had significant establishment and growth by the first rating event in August 2018, resulting in 70 to 82% cover (Table 5). The rapid establishment via seed was not to be expected in a nonirrigated setting. Zoysiagrass seed planted in May was able to achieve 70% coverage only 11 WAP (Table 5). In the first 4 WAP in May of year 1, 6.6 cm of rain fell in Yadkin County and 4.5 cm of that came within 1 WAP. The planting in March received the most precipitation during the first 4 WAP in year 1, with 11.1 cm and seed planted then achieved 78% cover 19 WAP (Table 5). Compadre sprigs established more readily from March April, May, and November plantings, ranging from 20 to 33% coverage when rated in August 2018 (Table 5). All plantings of Crowne sprigs achieved ≤ 10% coverage by the same time. Prior to the first rating event, fall plantings received two application of 24.4 kg ha^{-1} N (25% N – 5% P_2O_5 – 10% K_2O) in May and June of 2018 while spring plantings only received one application made in June 2018 (Table 3). Although it was not tested for, the additionally fertilizer application made to fall plantings in year 1 did not improve establishment as spring plantings contained greater zoysiagrass coverage compared to fall plantings, when averaged across all planting materials and each month within respective seasons (data not shown).

By September 2018, all plantings of Compadre sprigs were able to double or triple their coverage since the previous rating in August 2018. However, March, April, and May plantings expanded the most with 68%, 62% and 67% coverage, respectively (Table 5). At the end of the first complete growing season in year 1 (September), May and March seed plantings reached 98% and 95% coverage in less than 18 and 26 WAP, respectively (Table 5). However, November (89%), October (87%), April (85%), and September (82%) plantings from seed were as effective as May and March plantings and showed greater coverage than any sprig planting by September 2018 (Table 5). These results address the issue presented by Patton et al. (2004b) related to early year planting; that zoysiagrass can be seeded before June 1 and provide adequate coverage by the first frost. However, it should be noted the experimental areas in field trials conducted by Patton et al. (2004b) were irrigated as needed to encourage germination and establishment.

Following winter dormancy, monthly ratings resumed in June 2019 for year 1. Zoysiagrass coverage continued to increase with no signs of winter injury. Zoysiagrass seed planting in May (year 1) was the first planting month × planting material treatment to achieve complete coverage (100%) as of June 2019 while similar results were observed for all other monthly plantings of seed and ranged from 92 to 98% coverage (Table 5). By June 2019, all monthly plantings of Compadre sprigs contained 70 to 80% coverage, with the exception of October (Table 5). Crowne sprigs achieved a twofold increase in coverage for all monthly plantings except September, by June 2019. This can be attributed to less weed competition as oxadiazon was applied to year 1 planting in February 2019, along with 48.8 kg ha^{-1} N being applied in May 2019 (Table 3). Zoysiagrass establishment during year 1 in Yadkin was most successful when planted in March, April, and May, ranging from 90 to 95% coverage by the end of data collection (July 2018) when averaged across planting materials (Figure 4). All year 1 plantings of zoysiagrass seed in Yadkin achieved 100% coverage by July 2019 (Table 5). Additionally, March, April, May, and September plantings of Compadre sprigs showed similar results to seed plantings and ranged from 92 to 97% coverage by July 2019 (Table 5). Crowne sprigs planted in April and March also showed similar coverage to those previously mentioned, with approximately 87% coverage by July 2019.

Before data collection began in year 2, fall plantings received an application of oxadiazon at 3.3 kg ha^{-1} while spring plantings did not. Zoysiagrass planted in April resulted in more coverage (P<0.0001) at all monthly ratings compared to the remaining planting months (Figure 5). Zoysiagrass seed planted during April was able to achieve 73% coverage by August 2019, 16 WAP, which is the exact coverage this planting achieved in year 1 (Table 6). During year 2 in Yadkin County, the April planting received the least amount of precipitation (4.9 cm) within the first 4 WAP. Additionally, a total of 13.7 cm of rain fell in the 4 WAP in May of year 2, followed by 16.1 cm of rain that fell during remainder of June 2019. The spring planting during year 2 were planted at the second location utilized in Yadkin County, NC and notes taken during the first two rating events indicated there was an abundance of Johnsongrass [*Sorghum halepense* (L.) Pers.] within the plots that was not visible at the time of planting. Initial coverage from all monthly plantings of Compadre and Crowne sprigs was comparatively lower than year 1 with all plantings containing ≤ 8% coverage prior to entering winter dormancy (Table 6). By September 2019, the April seeding had the greatest coverage (80%) compared to all other plantings. At the end of data collection (July 2020) in year 2, seed planting in April and May contained more coverage (P<0.0001), 100% and 98%, respectively, than all other planting month × planting material treatments (Table 6). The remaining monthly seed plantings ranged from 53 to 72% coverage, while Compadre and Crowne sprigs ranged from 12 to 45% and 9 to 72% coverage, respectively.

Lenoir County, NC

Analysis of variance determined significant planting month × planting material interactions for all monthly zoysiagrass cover estimates collected during year 1 in Lenoir County, NC. Compadre and Crowne sprig plantings achieved minimal establishment during year 1, resulting in < 15% coverage for all monthly plantings by the end of data collection (Table 7). Seed plantings in year 1 had greater percent cover for all monthly plantings compared to both sprig materials. Optimum planting months in year 1 were March, November, and October, ranging from 18 to 27% zoysiagrass coverage when averaged across planting materials (Figure 6). Seed planted in March and November showed the most initial coverage with 23% and 18% by August 2018, respectively (Table 7). Plantings in March of year 1, received 12.4 cm of rainfall within 4 WAP. One month later, March and November seed plantings were similar to October planted seed and had more coverage than all other plantings, prior to winter dormancy, with 35%, 32%, and 26% coverage, respectively. All materials planted in May, during year 1, failed to establish prior to the first frost, despite receiving the most rainfall (16.9 cm) in the 4 WAP. By the end of data collection in year 1 (July 2019), seed planted in March and November achieved significantly greater coverage at 63% and 53%, respectively (Table 7). October planted seed had 39% coverage, which was the only other experimental unit to contain > 30% zoysiagrass coverage by July 2019.

All year 2 plantings of Compadre sprigs had ≤ 16% coverage by the end of data collection, and < 10% zoysiagrass coverage was achieved by all materials planted in May (Table 8). Significant planting month × planting material interactions were detected for zoysiagrass cover estimates recorded during August and September 2019 in year 2; although all coverage was < 3% prior to entering winter dormancy (data not shown). Despite little to no initial establishment from all plantings, Crowne sprig plantings in year 2 were the only vegetative material to show equal to or greater coverage than seed plantings as a whole. Zoysiagrass growth resumed in the spring of 2020 and analysis of variance identified differences between planting months and planting materials for cover estimates taken in June and July 2020. By the end of data collection in year 2, March and September represented the best months to plant zoysiagrass, regardless of planting material, resulting in 37% and 33% zoysiagrass cover, respectively (Figure 7). Plantings in March resulted in both seed and Crowne sprigs achieving 50% coverage by July 2020 and September plantings were at 42% cover from seed and 40% cover from Crowne sprigs at the end of data collection; all of which were significantly greater than remaining treatments (Table 8).

Conclusion

Results from this field research provide evidence that both seed and sprigs can be used to establish zoysiagrass (*Z. japonica*) with minimal inputs across varying environmental conditions present on North Carolina roadsides. Greater zoysiagrass coverage, overall, was observed in Yadkin County compared to Lenoir County, NC, likely because of major soil differences between locations.

Zoysiagrass seed showed accelerated establishment and greater percent coverage for all monthly plantings throughout data collection, with the exception of year 2 in Lenoir County. These results contradict previous research in which zoysiagrass seeding were not recommended in low input situation on NC roadsides. Gannon et al. (2016) concluded that zoysiagrass seed failure from March, April, and May plantings was likely due in part to a combination of non-ideal soil conditions, inadequate moisture inputs, and existing plant competition present on NC roadside. Similar conditions were experienced during the presented research which resulted in no seed failure and > 70% coverage in less than 5 months for the same plant timings. Late spring to early summer is typically suggested for seeding dates of warm-season grasses, which agrees with research findings. However, after one calendar year, fall and spring seed plantings showed similar coverage. Although establishment and coverage from sprigging material was not rapid, it should be noted that zoysiagrass sprigs were able to show comparatively similar coverage to seed plantings after about 12-15 months.

It is important to note that zoysiagrass growth began under non-ideal conditions (Figures 8 – 10) and was able to outcompete weeds and produced a weed-free sward of zoysiagrass in ≤ 2 years. On roadsides, this ability is very important as heavy weed infestation is typical for roadsides in NC and may pose threats by reduced line-of-sight and increasing maintenance cost. As zoysiagrass coverage continued, the presence of weeds and other vegetation began to decrease and were absent once zoysiagrass achieved complete coverage (100%). Implications from the presented research indicate that seed may be the most effective route for zoysiagrass establishment on NC roadsides. Additionally, zoysiagrass establishment on roadsides and under guardrails has potential value that may not be quantified, such as continuous spread and growth and minimal maintenance during dormancy, as well as, increased safety due to lower need for worker presence during maintenance. Future research should evaluate the inclusion of additional seeding rates as well as the use of companion crops at planting to reduce soil erosion and seed run-off. Current NCDOT seed mix and fertilizer/lime recommendations should also be evaluated to include zoysiagrass seed as an addition or possible replacement for bermudagrass seed.

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Table 1. Soil characteristics at research locations.

Location	Series	Texture	Taxonomic class	% of location†
Lenoir County, NC	Blanton	Sand	Loamy, siliceous, semiactive, thermic Grossarenic Paleudults	35
---	Wagram	Loamy sand	Loamy, kaolinitic, thermic Arenic Kandiudults	65
Yadkin County, NC‡	Clifford	Fine sandy loam	Fine, kaolinitic, mesic Typic Kanhapludults	80
---	---	Sandy clay loam	---	8
---	Delila	Fine sandy loam	Fine, mixed, active, mesic Typic Endoaquults	12
Yadkin County, NC§	Clifford	Sandy clay loam	Fine, kaolinitic, mesic Typic Kanhapludults	38
---	Fairview	Clay loam	Fine, kaolinitic, mesic Typic Kanhapludults	42
---	---	Fine sandy loam	Fine, kaolinitic, mesic Typic Kanhapludults	20

† Data obtained from the United States Department of Agriculture Natural Resources Conservation Service.

‡ First site utilized in Yadkin County, NC (36°06'57.0" N, 80°46'21.8" W).

§ Additional site needed in Yadkin County, NC (36°06'43.2" N, 80°34'10.1" W).

Table 2. Zoysiagrass planting dates in Lenoir and Yadkin County, NC during both years.

	Year 1					
Location	September	October	November	March	April	May
	Fall 2017			Spring 2018		
Lenoir	9/22	10/17	11/16	3/22	4/25	5/23
Yadkin	9/28	10/18	11/17	3/29	4/26	5/24
	Year 2					
	Fall 2018			Spring 2019		
Lenoir	9/25	10/15	11/8	3/21	4/18	5/9
Yadkin	9/26	10/17	11/7	3/22	4/17	5/15

Table 3. Fertilizer application dates and rates for Lenoir and Yadkin locations during both years.

	Year 1		Year 2	
Application dates†	Fall 2017	Spring 2018	Fall 2018	Spring 2019
May 2018	24.4‡			
June 2018	24.4	24.4		
May 2019	48.8	48.8	48.8	
July 2019			48.8	48.8
May 2020			48.8	48.8
June 2020				48.8
Total N	97.6	73.2	146.4	146.4

† Applications were made at both locations (± 7 days) to respective plantings.

‡ kg ha^{-1} N using 25% N – 5% P_2O_5 – 10% K_2O granular fertilizer (25-1.1-8.3; N-P-K).

Table 4. Analysis of variance for zoysiagrass cover. Includes test df (numerator df) and error df (denominator df) for the F-test and corresponding p-value.

Source of Variation	Numerator df	Denominator df	*F*-value	*p*-value
Year, Y†	1	6	323.96	<0.0001
Location, L‡	1	6	990.39	<0.0001
Y × L	1	6	194.94	<0.0001
Month, M§	5	40	14.88	<0.0001
Y × M	5	40	7.36	<0.0001
L × M	5	40	26.89	<0.0001
Y × L × M	5	40	7.70	<0.0001
Material, T¶	2	96	403.39	<0.0001
Y × T	2	96	58.48	<0.0001
L × T	2	96	157.58	<0.0001
M × T	10	96	2.71	0.0056
Y × L × T	2	96	17.74	<0.0001
Y × M × T	10	96	7.86	<0.0001
L × M × T	10	96	4.04	0.0001
Y × L × M × T	10	96	5.41	<0.0001
Ratings (Year), R(Y)#	6	432	620.63	<0.0001
L × R(Y)	6	432	160.43	<0.0001
M × R(Y)	30	432	4.48	<0.0001
T × R(Y)	12	432	21.73	<0.0001
L × M × R(Y)	30	432	9.65	<0.0001
L × T × R(Y)	12	432	30.64	<0.0001
M × T × R(Y)	60	432	6.48	<0.0001
L × M × T × R(Y)	60	432	6.05	<0.0001

† Year, Y = 2017-18 and 2018-19.

‡ Location, L = Lenoir and Yadkin County, NC.

§ Month, M = Planting months (September, October, November, March, April, and May)

¶ Material, T = ‘Compadre’ and ‘Crowne’ sprigs, and ‘Compadre’ (year 1) or ‘Zenith’ (year 2) seed.

Ratings, R(Y) = Monthly rating during the growing season (within year).

Table 5. Cover estimates of zoysiagrass planting material planted in three fall and three spring months in Yadkin County, NC during year 1 (2017-18).

Planting Material	Planting Month	—Aug. 2018—	—Sept. 2018—	—Jun. 2019—	—Jul. 2019—
		% cover†			
Compadre seed	Sept.	58 b‡	82 abc	97 a	100 a
	Oct.	33 cd	87 ab	98 a	100 a
	Nov.	82 a	89 a	95 ab	100 a
	Mar.	78 a	95 a	97 a	100 a
	Apr.	73 ab	85 abc	92 abc	100 a
	May	70 ab	98 a	100 a	100 a
Compadre sprig	Sept.	18 defg	38 ef	70 def	92 ab
	Oct.	3 fg	8 gh	27 i	60 e
	Nov.	23 cde	42 e	70 def	82 bcd
	Mar.	33 cd	68 bcd	78 cde	93 ab
	Apr.	37 c	62 d	80 bcd	97 a
	May	20 cdef	67 cd	75 de	97 a
Crowne sprig	Sept.	2 g	2 h	5 j	10 g
	Oct.	3 fg	16 gh	37 hi	70 ed
	Nov.	2 g	10 gh	27 i	43 f
	Mar.	9 efg	20 fgh	63 ef	87 abc
	Apr.	10 efg	13 gh	55 fg	88 ab
	May	2 g	22 fg	47 gh	73 cde

† Zoysiagrass cover estimated on a 0 (no cover) to 100% (complete cover) scale.
‡ Means within columns followed by the same letter are not significantly different at a probability level of 0.05.

Table 6. Cover estimates of zoysiagrass planting material planted in three fall and three spring months in Yadkin County, NC during year 2 (2018-19).

Planting Material	Planting Month	—Aug. 2019—	—Sept. 2019—	—Jun. 2020—	—Jul. 2020—
		% cover†			
Zenith seed	Sept.	6 d‡	20 d	48 cd	53 cd
	Oct.	25 bc	43 b	65 b	72 b
	Nov.	8 d	13 de	48 cd	62 bcd
	Mar.	32 b	32 c	53 bc	68 bc
	Apr.	73 a	80 a	100 a	100 a
	May	18 c	23 cd	94 a	98 a
Compadre sprig	Sept.	1 d	2 ef	23 ef	25 fg
	Oct.	0 d	1 f	8 fg	12 g
	Nov.	1 d	1 ff	10 fg	14 g
	Mar.	1 d	1 f	6 g	15 g
	Apr.	1 d	3 ef	35 de	45 de
	May	0 d	0 f	13 fg	20 fg
Crowne sprig	Sept.	3 d	5 ef	33 de	35 ef
	Oct.	0 d	0 f	7 fg	9 g
	Nov.	2 d	4 ef	10 fg	12 g
	Mar.	2 d	2 ef	10 fg	17 g
	Apr.	5 d	8 ef	60 bc	72 b
	May	0 d	1 f	12 fg	19 fg

† Zoysiagrass cover estimated on a 0 (no cover) to 100% (complete cover) scale.
‡ Means within columns followed by the same letter are not significantly different at a probability level of 0.05.

Table 7. Cover estimates of zoysiagrass planting material planted in three fall and three spring months in Lenoir County, NC during year 1 (2017-18).

Planting Material	Planting Month	—Aug. 2018—	—Sept. 2018—	—Jun. 2019—	—Jul. 2019—
		% cover†			
Compadre seed	Sept.	9 cd‡	19 bc	25 bc	28 cd
	Oct.	14 bc	26 ab	36 ab	39 bc
	Nov.	18 ab	32 a	47 a	53 ab
	Mar.	23 a	35 a	50 a	63 a
	Apr.	6 de	13 cd	24 bc	26 cde
	May	0 e	1 e	2 d	3 f
Compadre sprig	Sept.	2 e	5 de	10 cd	14 def
	Oct.	1 e	1 e	5 d	8 f
	Nov.	3 de	5 de	11 cd	13 def
	Mar.	2 de	4 de	8 d	12 ef
	Apr.	1 e	3 de	6 d	9 f
	May	0 e	0 e	2 d	2 f
Crowne sprig	Sept.	1 e	2 e	3 d	5 f
	Oct.	1 e	2 de	6 d	7 f
	Nov.	3 de	3 de	6 d	7 f
	Mar.	1 e	2 e	4 d	6 f
	Apr.	2 de	5 de	8 d	11 ef
	May	0 e	0 e	2 d	2 f

† Zoysiagrass cover estimated on a 0 (no cover) to 100% (complete cover) scale.
‡ Means within columns followed by the same letter are not significantly different at a probability level of 0.05.

Table 8. Cover estimates of zoysiagrass planting material planted in three fall and three spring months in Lenoir County, NC during year 2 (2018-19).

Planting Material	Planting Month	Jun. 2020	Jul. 2020
		% cover†	
Zenith seed	Sept.	9 bcd‡	42 ab
	Oct.	5 def	15 cdef
	Nov.	5 def	25 bcde
	Mar.	13 abc	50 a
	Apr.	1 f	12 cdef
	May	4 def	9 ef
Compadre sprig	Sept.	7 def	16 cdef
	Oct.	2 ef	6 f
	Nov.	4 def	13 cdef
	Mar.	2 ef	10 def
	Apr.	1 f	5 f
	May	1 f	3 f
Crowne sprig	Sept.	15 ab	40 ab
	Oct.	8 cde	28 bcd
	Nov.	15 ab	30 bc
	Mar.	17 a	50 a
	Apr.	5 def	14 cdef
	May	5 def	6 f

† Zoysiagrass cover estimated on a 0 (no cover) to 100% (complete cover) scale.
‡ Means within columns followed by the same letter are not significantly different at a probability level of 0.05.

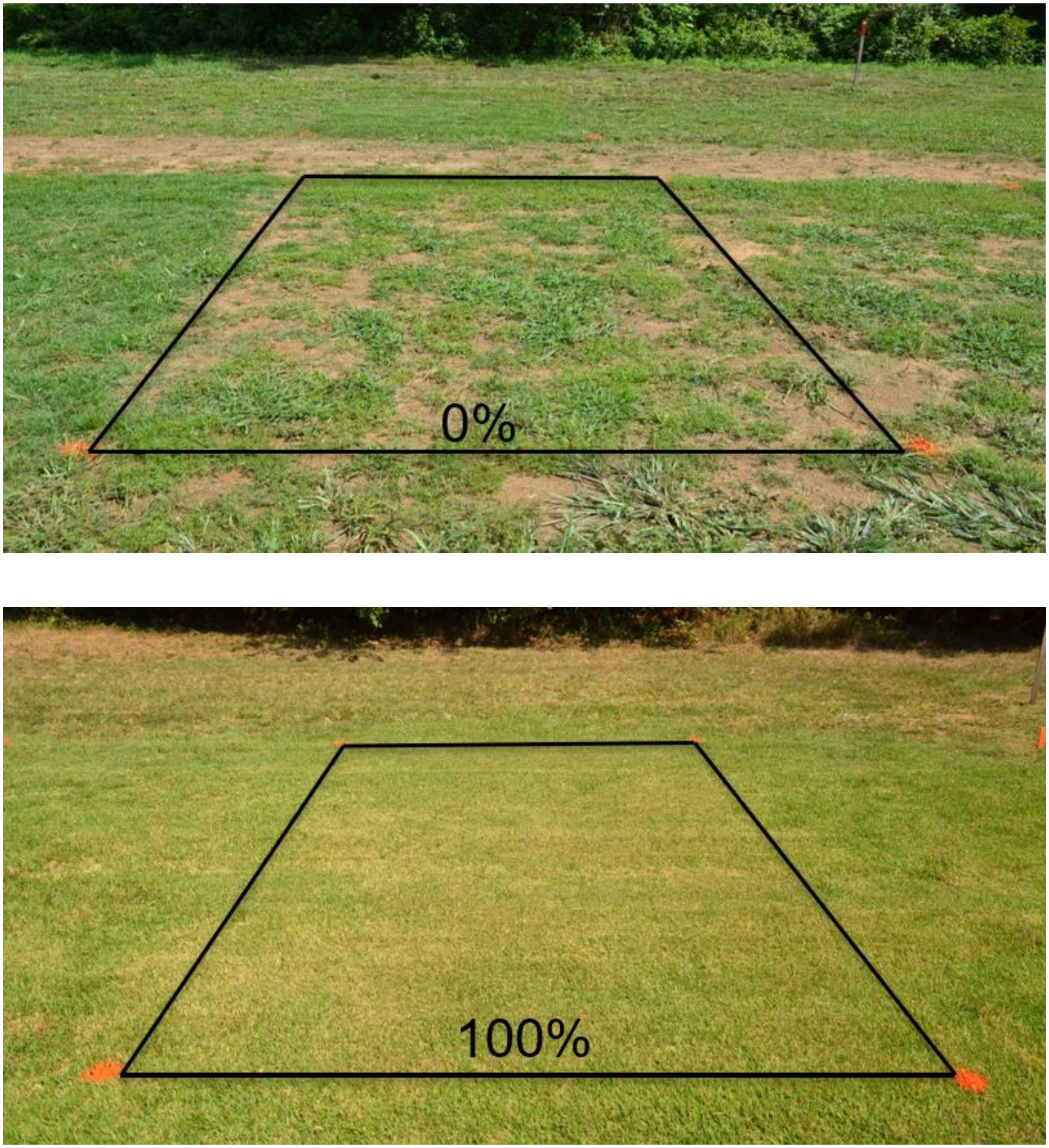

Figure 1. Visual representation of 0% and 100% zoysiagrass coverage.

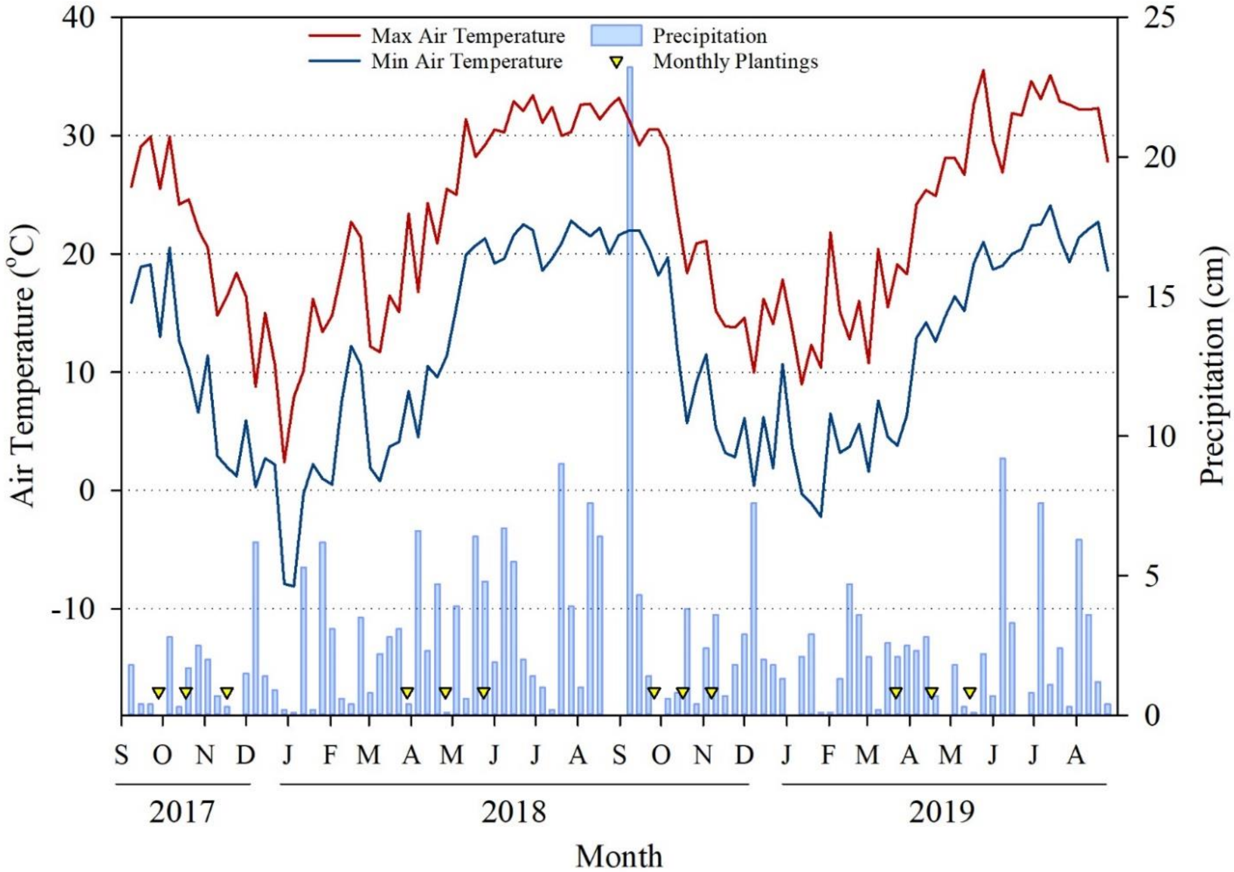

Figure 2. Maximum and minimum weekly average air temperatures and cumulative weekly precipitation during both years of planting in Lenoir, NC.

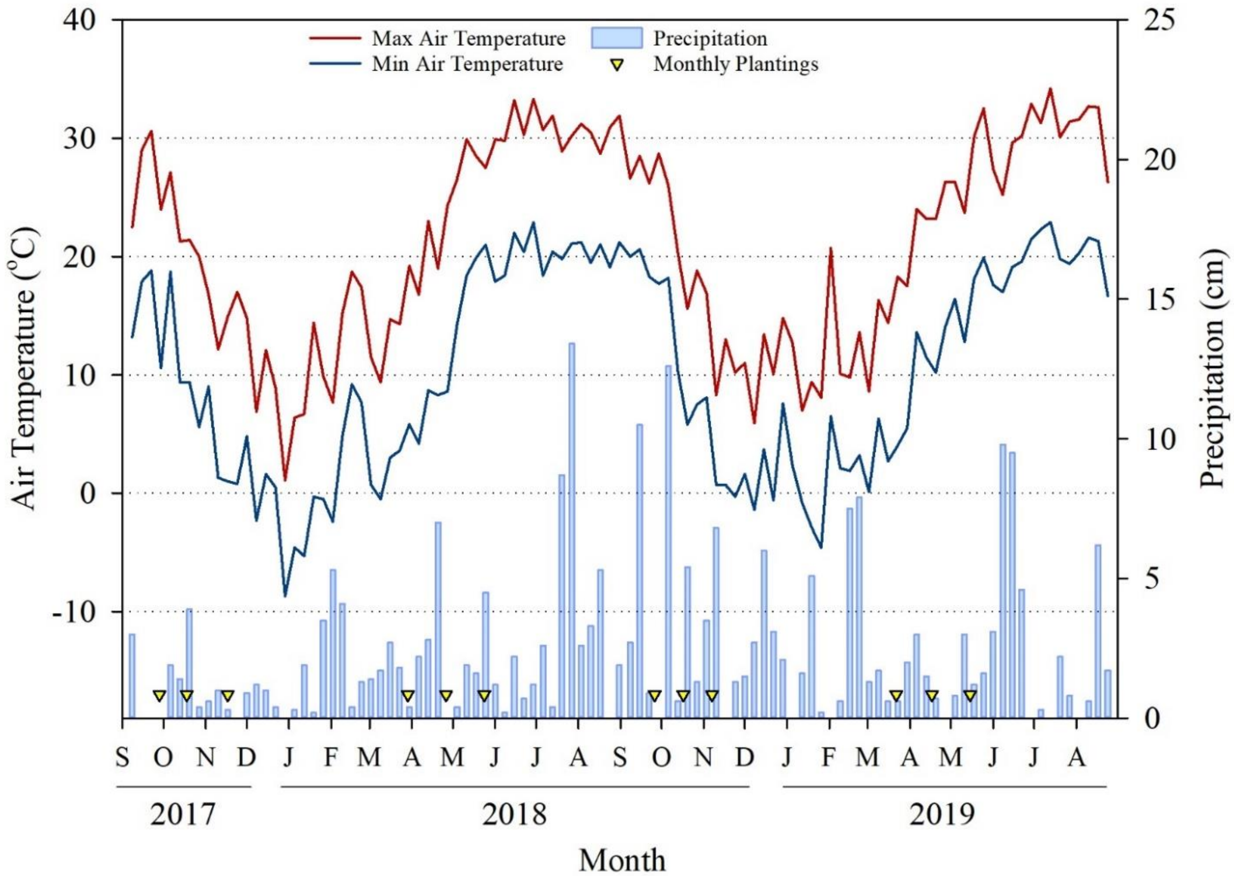

Figure 3. Maximum and minimum weekly average air temperatures and cumulative weekly precipitation during both years of planting in Yadkin, NC.

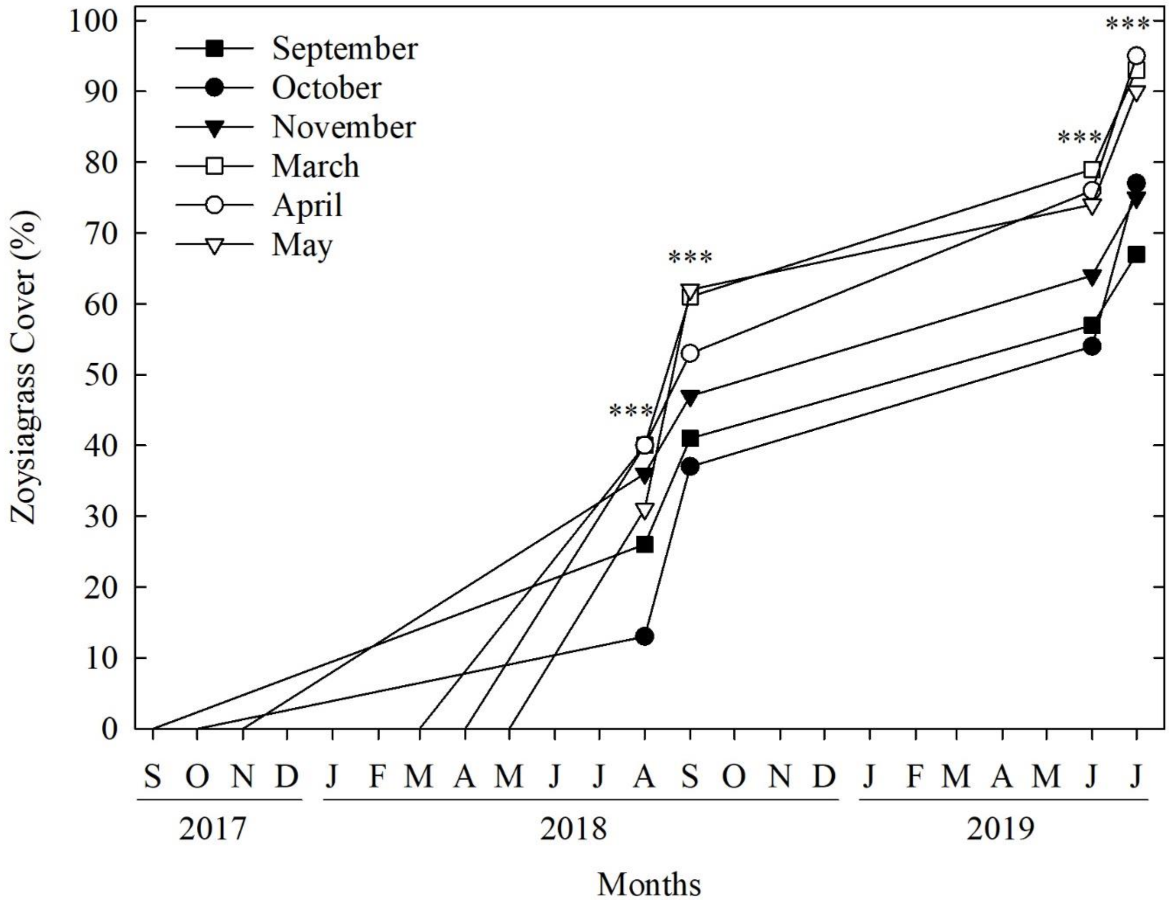

Figure 4. Percent zoysiagrass cover for year 1 planting months (averaged across planting material) in Yadkin County, NC. Lines originate on the planting date with data points corresponding to monthly ratings in August and September (2018) and June and July (2019). Significance at $P \leq 0.01$ and $P \leq 0.001$ levels denoted by **, *** above monthly ratings, respectively.

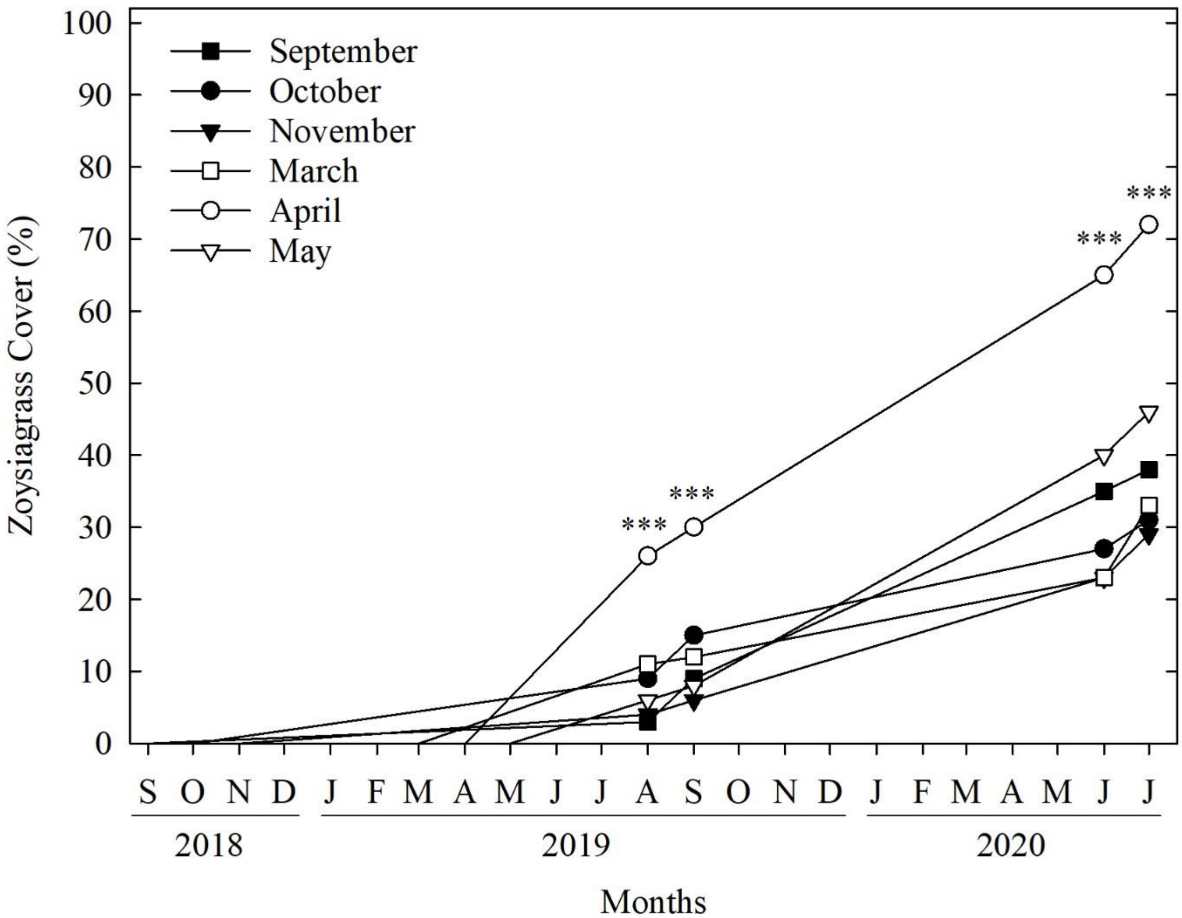

Figure 5. Percent zoysiagrass cover for year 2 planting months (averaged across planting material) in Yadkin County, NC. Lines originate on the planting date with data points corresponding to monthly ratings in August and September (2019) and June and July (2020). Significance at P ≤ 0.01 and P ≤ 0.001 levels denoted by **, *** above monthly ratings, respectively.

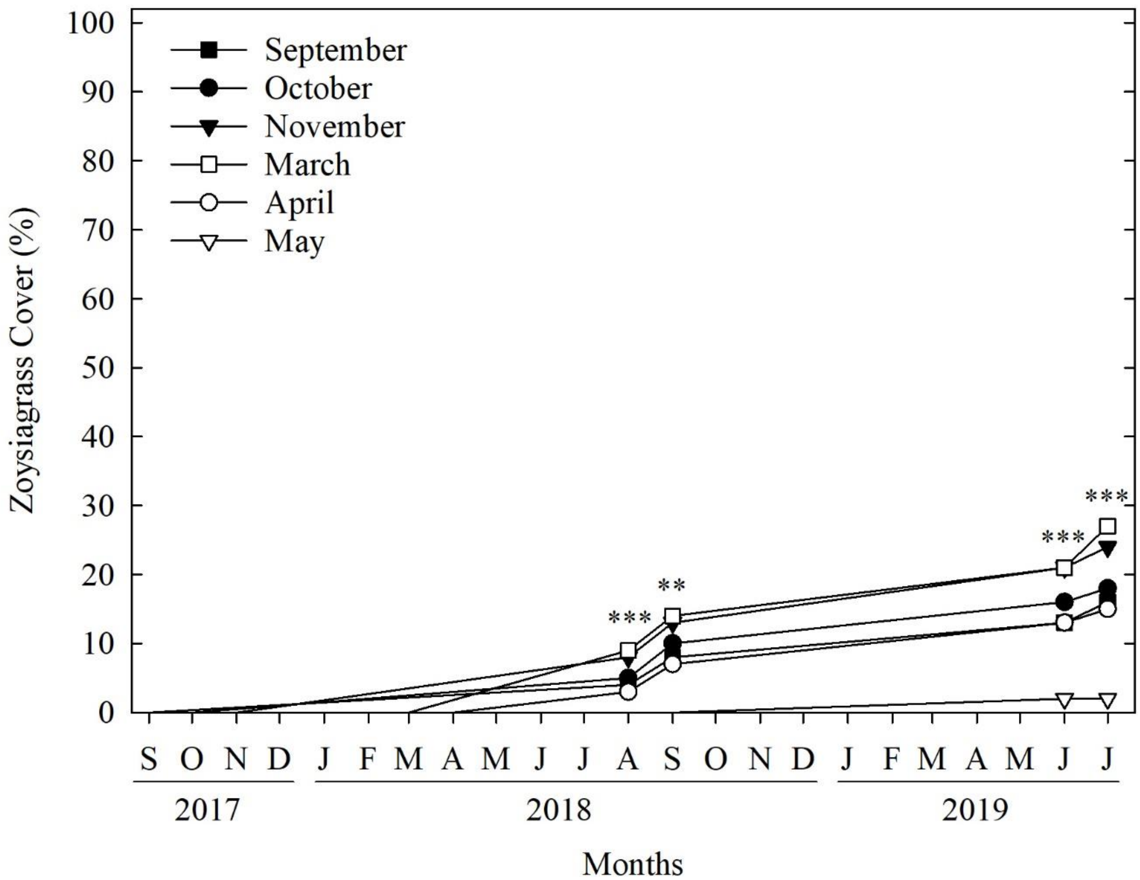

Figure 6. Percent zoysiagrass cover for year 1 planting months (averaged across planting material) in Lenoir County, NC. Lines originate on the planting date with data points corresponding to monthly ratings in August and September (2018) and June and July (2019). Significance at $P \leq 0.01$ and $P \leq 0.001$ levels denoted by **, *** above monthly ratings, respectively.

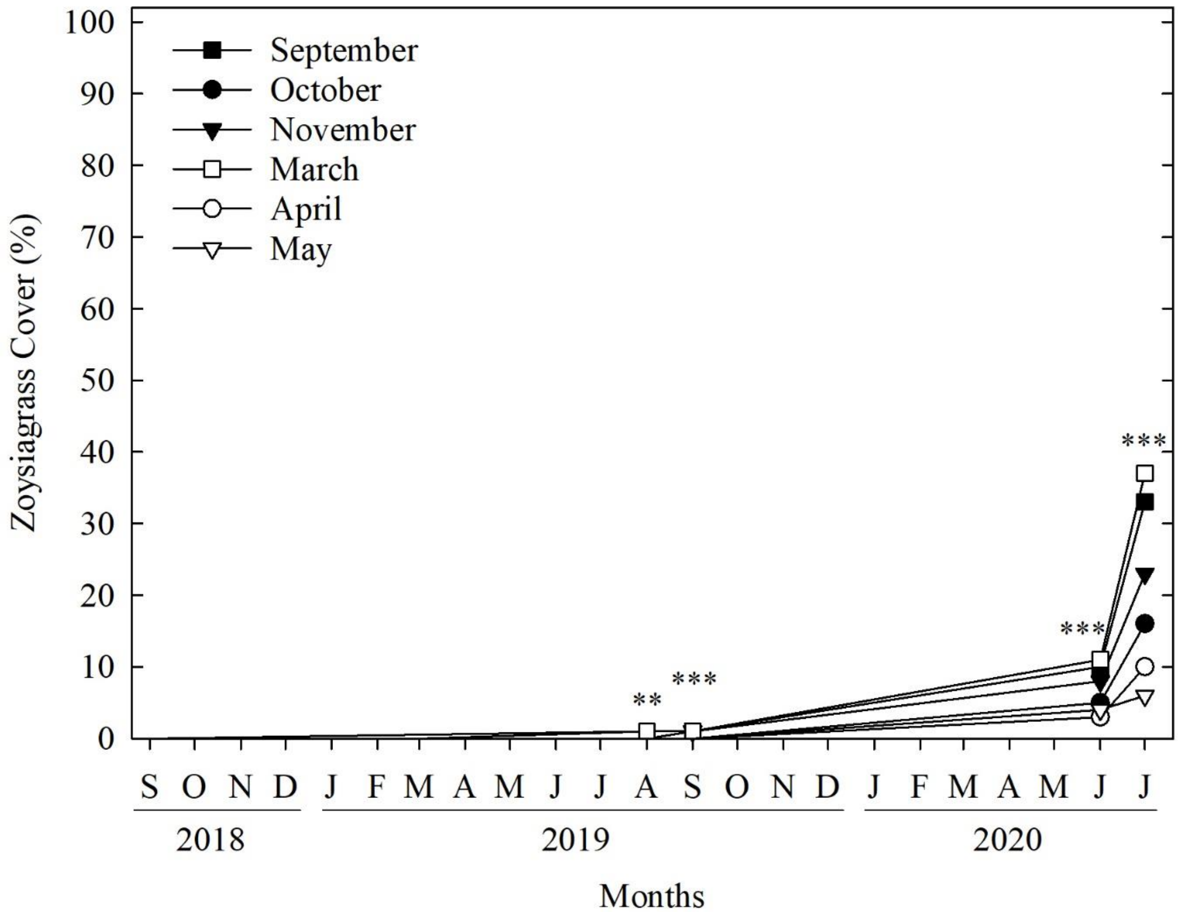

Figure 7. Percent zoysiagrass cover for year 2 planting months (averaged across planting material) in Lenoir County, NC. Lines originate on the planting date with data points corresponding to monthly ratings in August and September (2019) and June and July (2020). Significance at $P \leq 0.01$ and $P \leq 0.001$ levels denoted by **, *** above monthly ratings, respectively.

Figure 8. Non-ideal growing conditions found 9 WAP in April (left side of center white stake) and 5 WAP in May (right side of center white stake) in Yadkin County, NC during year 1.

Figure 9. Non-ideal growing conditions found 13 and 32 WAP in March and November of year 1 in Yadkin County, NC.

Figure 10. Non-ideal conditions found at the second location used in Yadkin County. Top image is one month after the May planting in year 2 in Yadkin County and the bottom image is two months after the same planting.

Chapter 2

Seasonal Evaluation of Large-Scale Equipment and Cover Materials for Zoysiagrass Sprig Establishment on North Carolina Roadsides

Abstract

Establishing uniform, perennial vegetation on a large area can be difficult to achieve, especially on roadside settings with minimal inputs. Additionally, Departments of Transportation seek to establish vegetation that is dense with slow vertical growth and minimal weed infestation in the most efficient and cost-effective manner. The objective of this study was to evaluate fall and spring zoysiagrass establishment using large-scale sprigging equipment on NC roadsides. Field research was initiated in the fall (October 2017 and 2018) and spring (May 2018 and 2019) in Lenoir and Rowan County, NC. Sprigging units consisted of an older, disk-driven sprigger that incorporated sprigs below the soil surface, a newer sprigger that left sprigs on the soil surface, and the new sprigger followed by post-sprig disking. 'Compadre' zoysiagrass (*Zoysia japonica* Steud.) sod rolls were fed into respective spriggers to apply sprigs onto 18.3 m × 1.5 m whole plots. Cover materials of excelsior mat, coastal bermudagrass straw, and an uncovered control were applied as split plots. In fall plantings of year 1, the new sprigger in Rowan, with and without disking resulted in the greatest coverage throughout this study; however, the old sprigger in Lenoir County resulted in coverage that was not different from the new sprigger in Rowan. Spring plantings in both years and fall plantings in year 2 were largely unsuccessful (≤15% coverage). Minimal differences among cover materials were present in both locations.

Results suggest the limitation in large-scale sprigging equipment use for establishing zoysiagrass may be impacted more by limited available water than the equipment.

Introduction

The North Carolina Department of Transportation (NCDOT) has one of the largest state-maintained highways systems in the United States consisting of over 660,000 acres of turfgrass (NCDOT, 2020). Establishing perennial vegetation is essential to control wind and water erosion of soil and eliminating dust and mud problems along roadsides. Roadside turf stands have the ability to reduce glare, air pollution, and heat buildup, as well as provide highway safety by serving as a stabilization zone for emergency stopping of vehicles (Beard, 1973). However, roadsides are a unique growing environment for turfgrass and can be challenging to establish and maintain (Watkins and Trappe, 2017). Due to climatic and soil limitations, the initial planting and establishment of turfgrass is often the most significant challenge for vegetation managers. The cut and fill slopes generated by past or present highway construction pose unique challenges to the vegetation managers (Booze-Daniels et al., 2000). Cut slopes will frequently expose a surficial weathered soil profile and then extend down into the underlying rock or sediments. Fill materials are often heavily compacted by earthmoving equipment to meet stability and strength specifications and lack the aggregation or structure that undisturbed soils possess (Booze-Daniels et al., 2000).

Zoysiagrass (*Zoysia* spp. Willd.) is an introduced, perennial, sod-forming species in the United States that is well adapted in the transitional and warm climatic regions. Over the past 40 years, throughout the transition zone, zoysiagrass use in home lawns has continued to increase due in part to its overall density, color, available textures, and reduced encroachment. Also, its superior cold tolerance compared to bermudagrass (Cynodon spp.) cultivars enables a broader environmental range for zoysiagrass utilization (Anderson et al., 2002). Zoysiagrass is also more tolerant to shaded environments, while bermudagrass is the least shade tolerant of all warm-season grasses (Emmons, 1995). Forbes and Ferguson (1947, 1984) made early mention about *Zoysia japonica* Steud. having special value in the “crabgrass belt,” an early euphemism for the transitional climatic zone. Cold winters create issues for warm-season grasses within the transition zone while hot, humid summers increase stress on cool-season grasses. Zoysiagrass is most commonly established vegetatively; although, the high cost of sod has led to an increased interest in sprig utilization to establish new stands. The disadvantages of zoysiagrass are few, but a slow growth rate, which delays establishment, is a common concerns. Its delayed establishment can lead to increases in initial maintenance costs, weed pressure, soil erosion issues, and plant desiccation because of delayed rooting; as well as, an overall reduction in associated aesthetics. Current literature primarily focuses on cultural practices to enhance zoysiagrass sprig establishment while relevant information regarding methods of sprig application, and sprigging dates are lacking. To date, little research has been conducted regarding roadside establishment of zoysiagrass in North Carolina, and none including large-scale equipment used for vegetative establishment under roadside conditions. Jefferies et al. (2017) found that zoysiagrass sod strips can be successfully used to establish turf (<60% coverage) along guardrails in NC and that December and March plantings were the most effective. Jefferies et al. (2017) observed poor results following sod establishment in April and May which was contributed to increased water demands at planting. The authors suggested that additional vegetative planting methods should be explored to reduce installation costs and minimize sod desiccation (Jefferies et al., 2017). Irrigation is applied to freshly laid sod in majority of turfgrass systems, however, this is not possible in a roadside setting and the expense to send a water truck out is high. Therefore, along roadsides, the period for successful sod establishment is comparably smaller than a home lawn or similar setting.

When renovating an area or establishing turf after construction, the NCDOT must provide temporary covers to prevent soil erosion until permanent vegetation becomes established. Temporary groundcovers applied after planting have proven to significantly reduce soil erosion and may enable greater vegetative cover compared to bare areas (McLaughlin and Brown, 2006). Babcock and McLaughlin (2011) evaluated the effects of straw applied at 2,240 kg ha^{-1} (2,000 lb ac^{-1}), straw at the same rate + 37 kg ha^{-1} PAM (polyacrylamide), and natural excelsior blankets on vegetation establishment and growth at six highway construction projects located in NC. Neither ground cover nor PAM application significantly affected biomass or vegetative cover at any of the six study sites (Babcock and McLaughlin, 2011). The authors concluded that establishment of vegetation was not affected by groundcover treatment but was highly correlated to the amount of rainfall and the temporal distribution of rainfall relative to planting date; suggesting it may be economical to provide temporary irrigation to initial stand establishment (Babcock and McLaughlin, 2011).

For roadside turf stands, the most desirable traits are rapid establishment and recuperative rates, tolerance to a variety of soil and nutrient conditions, freeze and drought tolerance, and a dense canopy to suppress weed encroachment. Characteristics pertinent to zoysiagrass establishment on roadsides include a low, prostrate growth habit, as well as favorable cold, drought, salt, and wear tolerances (Patton, 2009). Once established, zoysiagrass creates a dense and low-growing turf that spreads by an intergradation of thick stolons and rhizomes that form a very tight, tough, prostrate growing turf (Beard, 1973). The tight growth habit and high shoot density of healthy zoysiagrass swards allow relatively few weeds to colonize (Patton et al., 2017). The objective of this research was to evaluate various large-scale sprigging equipment applications during the fall and spring, for establishing zoysiagrass on North Carolina roadsides in efforts to reduce initial establishment cost and long-term maintenance of these areas. Also, a secondary objective was to evaluate the effects of natural excelsior mat and a straw cover on the establishment of zoysiagrass sprigs.

Materials and Methods

Field research was initiated October 2017 and May 2018 (year 1) and repeated the following year, Oct. 2018 and May 2019 (year 2), in Lenoir and Rowan County, NC. Lenoir County (35°18'08.6" N, 77°48'58.2" W) in the coastal plains region (USDA zone 8a) was chosen as an eastern site. The NCDA&CS Piedmont Research Station (35°41'45.5" N, 80°37'43.3" W) in Rowan County, NC (USDA zone 7b) was chosen as a western site. Soil textural classification of these sites are detailed in Table 1. A month prior to study initiation, the NC Department of Transportation (NCDOT) applied glyphosate (3.8 L a.i. ha^{-1}) as a burn down, followed by tillage to approximately 15 cm to control pre-existing vegetation at each site. Perennial grasses were present and warranted the high glyphosate rate (personal communication, Kevin Clemmer – NCDOT Roadside Vegetation Management Supervisor). For all plantings in this study, ‘Compadre’ zoysiagrass (*Z. japonica*) sod rolls measuring 1.5 m × 0.61 m × 0.02 m were harvested from Vandemark Sod Farms (Whitakers, NC) approximately 24 hours before use as the sprig source.

The NCDOT provided sod rolls, along with the necessary tractors, operators, and sprigging equipment to perform all plantings. Sprigging units utilized in this study consisted of an older, traditional sprigging unit (Sprig-ease 150, Vandemark Sod Farms, Whitakers, NC) which incorporates post sprig disking, and a new sprigging unit (Strickland Bros. Enterprises Inc., Spring Hope, NC) which leaves sprigs on top of the soil surface. Both units require personnel to stand on a back platform and continuously feed sod into the machines to ensure sprigs are applied to the plantings areas. In large-scale vegetative establishment, uniformity and functionality are important to the overall success of establishment. When applying sprigs via the old equipment, large amounts of dust clouds and soil debris accumulated around the sprigging unit, especially when the soil was dry. This creates non-ideal and potential hazardous situations for the workers feeding sod into the machine, as well as motorists traveling in close proximity. This was the rationale behind testing the new sprigger as minimal dust was produced when sprigs were pressed into the soil by vertical coulters. Sprigging equipment treatments included the traditional sprigging unit (old), the new sprigging unit (new), and the new sprigging unit followed by post-sprig disking (new disk). Post-sprig disking in the new disk treatment was completed by taking the old unit over the respective plots that were already sprigged. No additional sod was fed into the old unit during this disking. Taking the old sprigger over the respective area required additional time and fuel for the NCDOT; however, it reduced the human health risk factor from dust as workers were not standing on the back platform.

Sprigs were applied in the fall (17–19 October 2017 and 15-17 October 2018) and spring (2–3 May 2018 and 9–15 May 2019) of each year. Cover materials consisted of natural excelsior mat (Curlex CL Blankets, American Excelsior Company, Arlington, TX) (mat), coastal bermudagrass straw (straw) applied at 1 ton acre^{-1} (2241.7 kg ha^{-1}), and an uncovered control (none). This study was arranged in a split plot design with sprigging equipment as whole plots measuring 18.3 m × 1.5 m and cover material as subplots measuring 6.1 m × 1.5 m with four replications. During year 2 in Rowan County, whole plots were shortened (9.1 m × 1.5 m) because of excessively wet soil conditions at one end of the testing site. The rate of sprigs applied through each sprigging unit was targeted at a 1:15 – 1:20 expansion rate (area of sod:

area of ground). An average expansion rate of 1:18 was achieved throughout this research. The study area received no supplemental irrigation beyond natural rainfall.

Beginning one month after May plantings, sites were clipped with a rotary mower (Models: 74201 and 30284, The Toro Company, Bloomington, MN) at a 6.35-7.62-cm height of cut on a monthly basis during the growing season. Various applications of a granular fertilizer (25% N – 5% P_2O_5 – 10% K_2O) were made throughout the study, but never totaling more than 48.8 kg N ha^{-1} per calendar year (Table 2). In March 2018, oxadiazon [2-tert-butyl-4-(2,4 dichloro-5-isopropoxyphenyl)-2-1,3,4-oxadiazoline-5-one] (Oxadiazon 2G, Quali-Pro) was applied at a rate of 3.3 kg ha^{-1} to October 2017 plantings. In February 2019, oxadiazon was applied at the same rate as year 1 and October 2018 plantings.

Percent zoysiagrass cover was visually estimated on a 0 (no cover) to 100% (complete zoysiagrass cover) scale 41, 49, 85 and 90 weeks after fall plantings (WAFP) and 13, 21, 57, and 62 weeks after spring plantings (WASP) in year 1. Year 2 estimates were recorded 42 and 47 WAFP, along with 13 and 17 WASP. Only two cover estimates were taken the second year of sprigging due to termination of the allotted research area in Rowan County. Meteorological data was acquired from the closest weather station maintained by the North Carolina Climate Retrieval and Observation Network of the Southeast (CRONOS, 2014). East weather data was gathered from Cunningham Research Station (35°17'49.9" N, 77°34'26.4" W), approximately 22 km from the Lenoir plots. West data was collected from Piedmont Research Station (35°41'45.5" N, 80°37'43.3" W) where trials were being conducted.

This study analyzed sprigging equipment, cover materials, and season of sprigging in a combined analysis of location and year (Blouin et al., 2011) with multiple zoysiagrass cover rating dates analyzed. Zoysiagrass cover data were subjected to analysis of variance using the

PROC GLIMMIX procedure in the Statistical Analysis System software (version 9.4; SAS Inst. Inc., Cary, NC) to determine treatment effects and interactions. Significant year ($P \leq 0.0001$) and season of sprigging ($P \leq 0.0001$) interaction occurred (Table 3), therefore, data were sorted by year and season of sprigging and presented separately. Identified significant main effects and interactions were sorted and analyzed accordingly using Tukey-Kramer mean separation at a probability level of 0.05. Monthly progress in turfgrass establishment by the end of the first growing season (August and September) for both years, along with progress into early summer (June and July) for year 1, are presented as monthly means of percent zoysiagrass cover.

Results and Discussion

Environmental Influence

Significant interactions with year ($P \leq 0.0001$) and other factors occurred due to varying climatic conditions between years. Figures 1 and 2 illustrate those conditions in Lenoir and Rowan County, NC from October 2017 through August 2019. Both locations experienced cooler temperatures in the winter of 2017-18 compared to 2018-19 and rising spring temperatures came earlier in 2019 than 2018. However, the most likely cause in interactions with year was due to inconsistent precipitation between years as no supplemental irrigation was applied beyond natural rainfall. Significant interactions with season of sprigging ($P \leq 0.0001$) and other factors was due to constraining environments of fall (October) and spring (May) each year.

Fall Sprig Plantings

Sprigs planted in the fall of each year had minimal time to establish prior to winter dormancy; however, they were able to take advantage of early spring weather and resulted in greater zoysiagrass coverage throughout this research. Analysis of variance determined significant location × sprigging equipment interactions on zoysiagrass cover estimates evaluated 41, 49, 85, and 90 WAFP in year 1. Although differences were detected at 41 WAFP, minimal zoysiagrass establishment had occurred (< 8% coverage) at both locations, regardless of sprigging equipment used. For the remaining cover estimates recorded on sprigs planted in the fall during year 1, results varied among the top performing sprigging equipment at both locations. In Rowan County, the new sprigging unit, both with and without post sprig disking resulted in the greatest zoysiagrass coverage at 49, 85, and 90 WAFP. However, planting with the old sprigging unit in Lenoir County resulted in coverage that was not different ($P \leq 0.05$) from the new sprigger in Rowan County for those same rating events (Table 4). In Lenoir County, 6.9 cm of rain fell during the first 4 WAFP in year 1 while 8.3 cm of rain occurred in Rowan County for the same time. However, sprig regrowth was no likely to begin until the following spring.

In late September, 49 WAFP, sprigs applied via the new sprigging unit in Rowan County showed similar coverage, both with (31.3% coverage) and without (35.9%) post-sprig disking. At that same interval in Lenoir County, the old sprigging unit plantings had similar coverage (18.3%) to the new sprigging treatments in Rowan County (Table 4). Following winter dormancy, zoysiagrass cover estimates resumed in June 2019 for year 1 plantings in the fall and coverage continued to increase with no signs of winter injury. Sprigs planted with the old sprigger continued to show the most coverage in Lenoir County at 85 WAFP with 38.3% cover, while sprigs from the new sprigging unit in Rowan County had similar coverage and showed no effect of post-sprig disking; resulting in 45.4% cover without disking and 41.5% cover with disking (Table 4). At 90WAFP, applying the new sprigging unit in Rowan County provided the greatest regrowth from sprigs at 68.3% coverage without disking, and 57.1% coverage with post-sprig disking. Conversely, in Lenoir County, the old sprigging unit provided 45.4% coverage and was no different than the new sprigger (with or without post-sprig disking) in Rowan County at 90 WAFP (Table 4).

During the year 2 of fall sprig plantings, differences were detected among location × sprigging equipment interactions on zoysiagrass cover estimates recorded 47 WAFP; however, minimal establishment (< 6% coverage) had occurred. Differences may have been detected but the lack of overall coverage does not provide a strong biological significance. At 47 WAFP in year 2, the greatest zoysiagrass coverage was found in Rowan County when sprigs were applied below the soil surface via the old sprigger (5.4% coverage) and via the new sprigger with post sprig disking (4.6%) (Table 5). In Lenoir County, all sprigging units produced ≤ 2.4% coverage 47 WAFP in year 2.

Resulting differences in coverage between the sprigging units in Lenoir and Yadkin County were likely due in part to how the sprigs are laid and the major soil differences between locations (Table 1). The new and old sprigging units produce sprigs in a similar fashion; however, the old sprigger immediately incorporates the sprigs to an approximate depth of 2.54 – 3.81 cm (1 – 1.5 inches) (Vandemark, 2007). The depth of incorporation may have caused issues as Boyd et al. (2003) explained that heavy topdressing (> 1.0 cm depth) of ‘Meyer’ zoysiagrass sprigs may delay emergence and coverage. In Lenoir County, were the soil is dominated by sand-sized particles (≥ 70%), applying sprigs below the soil surface via the old unit provided the greatest zoysiagrass coverage throughout data collection in year 1. It should also be noted that sprigs applied from the new sprigger with post-sprig disking in Lenoir produced slightly more zoysiagrass coverage compared the new sprigger without disking. Sprigs below the soil surface had access to more available water for a longer time period and did not experience desiccation as quickly as sprigs left on the soil surface. However, sprigs planted with the new equipment, during year 1 in Rowan County, resulted in greater zoysiagrass coverage compared to the old equipment. In Rowan County, the soil has a much higher clay content than Lenoir County, therefore providing more available water at or near the soil surface which may minimize the moisture contribution from covering sprigs. That is likely the major contributing factor to the overall greater zoysiagrass coverage in Rowan County compared to Lenoir County, regardless of post sprig disking application.

Spring Sprig Plantings

The months following sprigs plantings in the spring were generally the hottest months of the year and precipitation was inconsistent throughout. This led to an overall reduction in zoysiagrass coverage from those sprigs planted in the spring of each year, and largely resulted in unsuccessful establishment. Analysis of variance determined significant location × sprigging equipment interactions on zoysiagrass cover estimates recorded 13, 21, 57, and 62 WASP in year 1. Differences were detected at 13 and 21 WASP; however, negligible coverage was achieved by all sprigging equipment in both locations resulting in < 4% zoysiagrass coverage prior to entering winter dormancy. In Lenoir and Rowan County, 15.6 cm and 13.8 cm of precipitation fell during the first 4 WASP; although, majority of that rain came between weeks 3 and 4 for both locations. For Lenoir County, a total of 15.6 cm of rain fell over the same time period Following dormancy, sprigs planted via the old sprigger in Rowan contained greater coverage (10.2% coverage), compared to all other sprigging equipment × location interactions at 57 WASP (Table 6). In Lenoir County, no differences were found between sprigging units at 57 WASP, as coverage ranged from 0.5 – 1.5%. At 62 WASP, sprigs planted in Rowan County via the old sprigging unit attained the greatest zoysiagrass cover with 15.0% coverage. By this time in Lenoir County, all sprigging units produced < 3% zoysiagrass coverage (Table 6).

During year 2 of sprigging in the spring, analysis of variance determined significant location × sprigging equipment interactions at 13 and 17 WASP; however, no zoysiagrass coverage was observed for sprigs planted in Lenoir County during year 2. Failure to show initial establishment is contributed to a lack of available water as only 3.3 cm on rain during the first 4 WASP in Lenoir County during year 2. Similar to year 1 spring plantings, sprigs applied via the old sprigger in Rowan County contained significantly more zoysiagrass (2.4% coverage) than any other sprigging equipment × location treatment by the end of data collection in year 2 (Table 7).

The overall poor establishment and coverage from sprigs planted in the spring are likely due in part to the lack of available water or consistent precipitation, coupled with rising temperatures shortly after planting. Boyd et al. (2003) explained how the first few weeks following zoysiagrass sprig application are critical to establishment and that it is important to protect the sprigs from desiccation until roots are formed and the sprigs can extract soil moisture. The sprigs planted in Rowan County during the spring of year 1 received 13.8 cm of precipitation during the first 4 WASP. However, precipitation was < 4 cm for the entire month of June which is also when air temperatures were the highest for all of 2018 (Figure 2). In Lenoir County, 15.6 cm of rain fell in the 4 WASP. Although Lenoir County received more cumulative rainfall than Rowan County during the spring of year 1, the major soil differences between locations likely led to Lenoir County having less plant available water than Rowan. Additionally, during year 2 of planting in the spring, only 3.3 cm on rain during the first 4 WASP in Lenoir County while Rowan County received < 2 cm of rainfall during the first 3 WASP and another 7.6 cm of rain during the 4th WASP. This likely caused sprig desiccation and mortality.

Cover Materials

There were no differences among cover materials × sprigging equipment interactions. Differences were detected for cover material × location interactions for both seasons of sprigging within both years; however, only data for the fall planting in year 1 are presented as minimal zoysiagrass coverage for remaining plantings does not provide strong biological significance. In Rowan County during year 1, sprigs planted in the fall resulted in greater coverage when they were covered by mat (65% coverage) or straw (59%) materials compared to sprigs left uncovered (33%) by then end of data collection. Conversely, no differences were detected in Lenoir County during the fall planting in year1 as all cover materials ranged from 33 – 35% zoysiagrass coverage by July 2019. These results agree with previous finding that the effects of straw and excelsior blanket groundcovers were not different for vegetative cover at six sites in NC; however, there were differences between locations (Babcock and McLaughlin, 2011). Cover materials have the potential to increase zoysiagrass sprig establishment, however they did not reduce zoysiagrass growth compared to the uncovered control.

Conclusion

Results from this field research indicate considerable differences exist among the individual and combined effects large-scale sprigging equipment use and the season of sprigging on zoysiagrass sprig establishment across varying environmental conditions present on North Carolina roadsides. Overall, greater zoysiagrass coverage was observed from sprigs applied in the fall compared to the spring, most likely due to unfavorable climatic conditions following spring sprigging. In nonirrigated settings, late spring and early summer months (May-July) generally have unfavorable climatic conditions for vegetative establishment and increase the risk of desiccation; which is the most probable cause for minimal coverage found in spring plantings of both years. Additionally, sprigs applied in Rowan County, NC achieved greater zoysiagrass coverage compared to Lenoir County, NC; most likely due to the major soil differences and respective water holding capacity.

The utilization of large-scale sprigging equipment to vegetatively establish zoysiagrass was explored by the NCDOT in efforts to reduce initial establishment cost compared to sodding. Different equipment designs were tested to reduce hazards working conditions and minimize dust accumulation. Mixed results were observed as the sprigging equipment that provided the greatest zoysiagrass coverage varied throughout the study. Although no clear 'winner' was determined for sprigging equipment performance, important ancillary information was obtained through their use. Overall, complications were observed in the use of both spriggers There were problems with sod getting stuck before being shredded and vison or line of sight issues for personnel feeding sod and tractor operator. Vision impairment of tractor operators is not typical for rear-mounted equipment. Additionally, due to the weight of sprigging units and the incorporation feature of the old sprigger, tractors and sprigging units would occasionally get stuck or bog down as soil would build up between the sprigger and tractor. Also, because of the size of sprigging units and tractors needed to operate them, there was limited maneuverability in getting the equipment into tight spaces.

Implications from the presented research indicate the limitation in use of large-scale sprigging equipment for vegetatively establishing zoysiagrass may be impacted more by limited available water than the equipment. However, utilization of zoysiagrass on roadsides can have long-term value such as continuous spread and growth once established and minimal maintenance during dormancy, as well as, increased safety due to less mowing and string trimming requirements. Further research should continue to evaluate options for large-scale equipment use, while potentially increasing water application during the first few weeks after planting.

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Table 1. Soil conditions at research location.

Location	Series	Texture	Taxonomic class	% of location†
Lenoir, NC	Blanton	Sand	Loamy, siliceous, semiactive, thermic Grossarenic Paleudults	35
---	Wagram	Loamy sand	Loamy, kaolinitic, thermic Arenic Kandiudults	65
Rowan, NC	Cecil	Sandy clay loam	Fine, kaolinitic, thermic Typic Kanhapludults	5
--	Lloyd	Clay loam	Fine, kaolinitic, thermic Rhodic Kanhapludults	95

† Data obtained from the United States Department of Agriculture Natural Resources Conservation Service.

Table 2. Fertilizer applications made for east and west locations during both years.

	Year 1		Year 2	
Application dates†	Oct. 2017	May 2018	Oct. 2018	May 2019
May 2018	24.4‡			
June 2018	24.4	48.8		
May 2019			48.8	
July 2019				48.8
Total N	48.8	48.8	48.8	48.8

† Applications were made at both locations (± 7 days) to respective plantings.

‡ kg ha^{-1} N using a granular fertilizer (25-5-10; N-P_2O_5-K_2O) (25-1.1-8.3; N-P-K).

Table 3. Analysis of variance for zoysiagrass cover. Includes test df (numerator df) and error df (denominator df) for the F-test and corresponding *p*-value.

Source of Variation†	Numerator df	Denominator df	*F*-value	*p*-value
Year, Y	1	12	56.52	<0.0001
Location, L	1	12	6.58	0.0310
Y × L	1	12	2.56	0.1428
Season, S	1	12	61.31	<0.0001
Y × S	1	12	43.14	<0.0001
L × S	1	12	2.4	0.1476
Y × L × S	1	12	1.12	0.3101
Equipment, E	2	48	0.37	0.6939
Y × E	2	48	0.1	0.9065
L × E	2	48	6.26	0.0039
Y × L × E	2	48	8.62	0.0006
S × E	2	48	1.54	0.2253
Y × S × E	2	48	1.97	0.1505
L × S × E	2	48	16.16	<0.0001
Y × L × S × E	2	48	15.14	<0.0001
Material, M	2	144	11.98	<0.0001
Y × M	2	144	5.81	0.0038
L × M	2	144	15.86	<0.0001
S × M	2	144	5.16	0.0068
E × M	4	144	0.44	0.7776
Y × L × M	2	144	8.21	0.0004
Y × S × M	2	144	2.53	0.0835
Y × E × M	4	144	0.86	0.4873
L × S × M	2	144	10.7	<0.0001
L × E × M	4	144	0.76	0.5529
S × E × M	4	144	1.15	0.3377
Y × L × S × M	2	144	6.11	0.0028
Y × L × E × M	4	144	0.84	0.5028
Y × S × E × M	4	144	1.22	0.3065
L × S × E × M	4	144	1.07	0.3729
Y × L × S × E ×M	4	144	0.96	0.4293
Ratings, R(Y × L)	8	568	61.63	<0.0001

† Year, Y = 2017-18 and 2018-19; Location, L = Lenoir and Rowan County, NC; Season, S = Fall and spring plantings; Equipment, E = Sprigging equipment; Material, M = Cover materials; Ratings, R(Y×L) = Rating dates (within year by location).

Table 4. Zoysiagrass cover estimates of sprigging equipment used in the fall (October) in Lenoir and Rowan County, NC during year 1 (2017).

Location	Sprigging Equipment	—Aug 2018— (41 WAFP)	—Sept. 2018— (49 WAFP)	—Jun. 2019— (85 WAFP)	—Jul. 2019— (90 WAFP)
		% zoysiagrass cover†			
Rowan	Old	3.7 ab‡	14.4 b	21.9 bc	31.1 cd
	New Disk	3.1 ab	31.2 ab	41.5 a	57.1 ab
	New	3.6 ab	35.9 a	45.4 a	68.3 a
Lenoir	Old	7.2 a	18.3 ab	38.3 ab	45.4 abc
	New Disk	2.0 b	10.2 bc	28.7 b	31.7 bcd
	New	1.0 b	4.1 c	20.4 bc	22.9 d

† Zoysiagrass cover estimated on a 0 (no cover) to 100% (complete cover) scale.
‡ Means within columns followed by the same letter are not significantly different according to Tukey-Kramer HSD (P = 0.05).

Table 5. Zoysiagrass cover estimates of sprigging equipment used in the fall (October) in Lenoir and Rowan County, NC during year 2 (2018).

Location	Sprigging Equipment	Aug 2019 (42 WAFP)	Sept. 2019 (47 WAFP)
		% zoysiagrass cover†	
Rowan	Old	3.1 a‡	5.4 a
	New Disk	2.5 a	4.6 ab
	New	1.7 a	3.0 bc
Lenoir	Old	1.1 a	2.4 bc
	New Disk	0.5 a	1.7 bc
	New	0.4 a	1.1 c

† Zoysiagrass cover estimated on a 0 (no cover) to 100% (complete cover) scale.
‡ Means within columns followed by the same letter are not significantly different according to Tukey-Kramer HSD (P = 0.05).

Table 6. Zoysiagrass cover estimates of sprigging equipment used in the spring (May) in Lenoir and Rowan County, NC during year 1 (2018).

Location	Sprigging Equipment	—Aug 2018— (13 WAFP)	—Sept. 2018— (21 WAFP)	—Jun. 2019— (57 WAFP)	—Jul. 2019— (62 WAFP)
		% zoysiagrass cover†			
Rowan	Old	1.3 a‡	3.1 a	10.2 a	15.0 a
	New Disk	0.4 b	1.1 b	3.0 b	4.2 b
	New	0.0 b	0.2 c	0.4 c	0.7 c
Lenoir	Old	0.2 b	0.9 bc	1.5 bc	2.1 bc
	New Disk	0.1 b	0.4 bc	0.5 c	1.7 bc
	New	0.2 b	0.6 bc	0.7 bc	1.1 bc

† Zoysiagrass cover estimated on a 0 (no cover) to 100% (complete cover) scale.
‡ Means within columns followed by the same letter are not significantly different according to Tukey-Kramer HSD (P = 0.05).

Table 7. Zoysiagrass cover estimates of sprigging equipment used in the spring (May) in Lenoir and Rowan County, NC during year 2 (2019).

Location	Sprigging Equipment	Aug 2019 (13 WAFP)	Sept. 2019 (17 WAFP)
		% zoysiagrass cover†	
Rowan	Old	0.8 a‡	2.4 a
	New Disk	0.0 b	0.1 b
	New	0.1 b	0.4 b
Lenoir	Old	0.0 b	0.0 b
	New Disk	0.0 b	0.0 b
	New	0.0 b	0.0 b

† Zoysiagrass cover estimated on a 0 (no cover) to 100% (complete cover) scale.
‡ Means within columns followed by the same letter are not significantly different according to Tukey-Kramer HSD (P = 0.05).

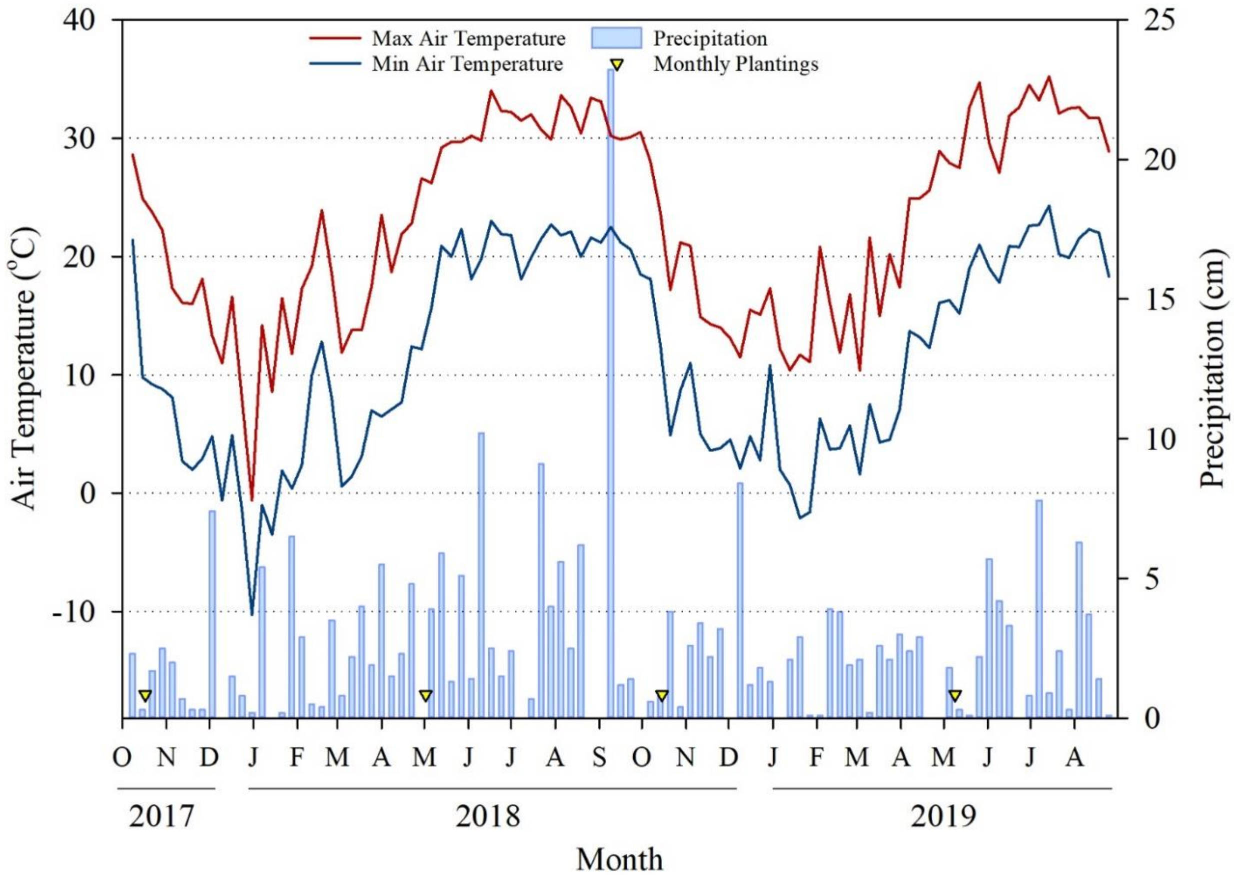

Figure 1. Maximum and minimum weekly average air temperatures and weekly cumulative precipitation during both years of sprigging in Lenoir, NC.

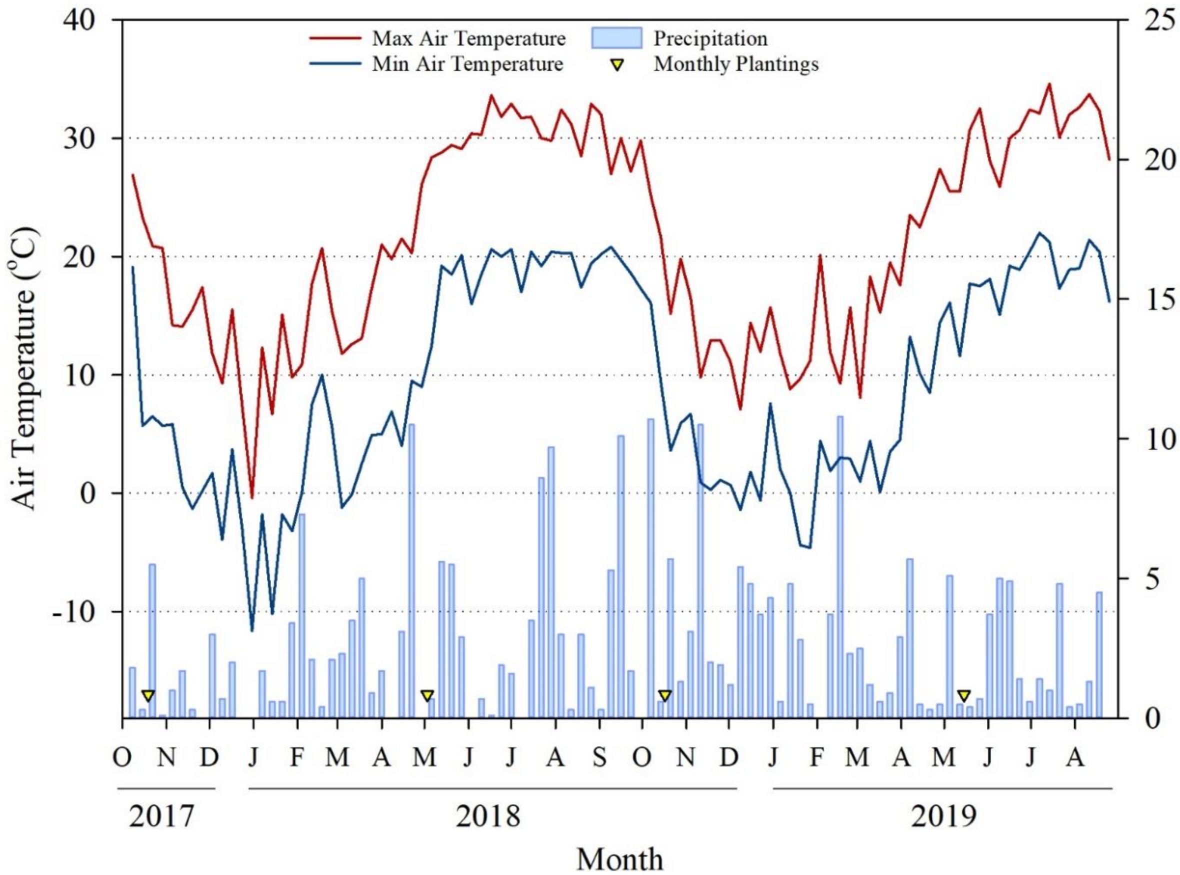

Figure 2. Maximum and minimum weekly average air temperatures and weekly cumulative precipitation during both years of sprigging in Rowan, NC.

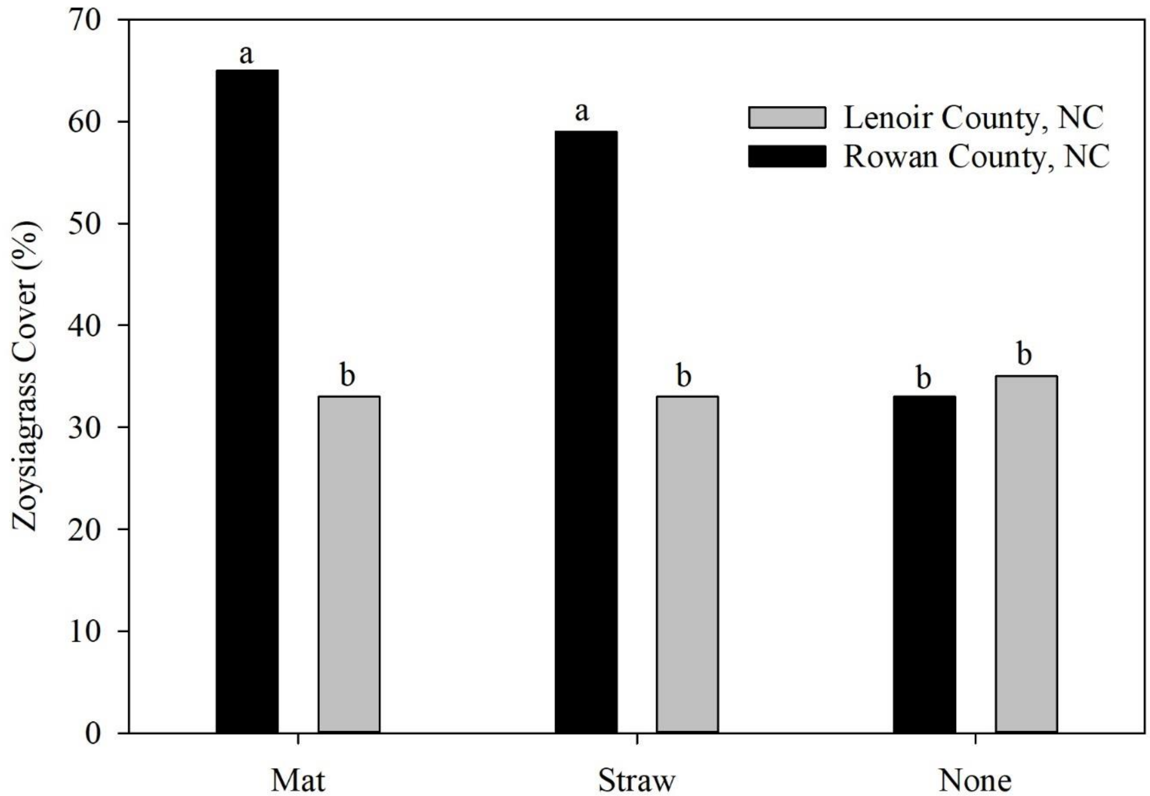

Figure 3. Percent zoysiagrass cover estimates in July 2019 for sprig cover materials utilized following fall plantings in year 1 (averaged across sprigging equipment) in both locations. Values with the same letter are not significantly different according to Tukey-Kramer HSD (P = 0.05).