RESEARCH & DEVELOPMENT

Selection, Installation, and Evaluation of Zoysiagrass

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Selection, Installation, and Evaluation of Zoysiagrass

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16. Abstract

In the past, NCDOT has used a combination of chemical and mechanical weed control management strategies under and around over 1000 miles of median rail that have proven to be time consuming and expensive to implement. Zoysiagrasses are known to be a thick sod-producing turfgrass that once adequately established have minimal weed invasion. Zoysiagrass germplasm that can be established quicker using sprigging methods may provide a solution to their establishment and long-term maintenance. Thus, this project was conducted to evaluate different varieties, methods and timings for establishment of zoysiagrass on roadsides. These evaluations were done on NC roadsides in different climatic regions of NC. For one objective, cultivars were seeded or sprigged at different timings (fall -September, October, November- or spring -March, April, May). Zoysiagrass planted via seed was faster to establish with greater coverage for both location and all timings compared to sprigging. 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 secondary objective was to evaluate fall and spring zoysiagrass establishment using two large-scale sprigging units: an older, disk-driven sprigger that incorporated sprigs below the soil surface, and a newer sprigging unit that leaves sprigs on the soil surface. Cover materials of excelsior mat, coastal bermudagrass straw, and an uncovered control were applied as split plots. Results suggest the limitation in large-scale sprigging equipment use for establishing zoysiagrass may be impacted more by limited available water than the type of equipment. For the third objective experimental materials were tested against commercial cultivars for their ability to establish faster under minimal inputs. Differences in establishment were identified and two experimental lines showed significant promise for us on NC roadsides. Overall, results from this research suggest that zoysiagrass can be established on NC roadsides with minimal inputs but additional research is needed to refine the methods to increase sprigging success.

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SUMMARY

This research project was conducted to assess different methods and timings for establishment of zoysiagrass on roadsides, and to evaluate establishment speed of new germplasm compared to cultivars available commercially. These evaluations were done on NC roadsides in different climatic regions of NC. 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. Using commercial cultivars, 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 just a few exceptions. These results contradict previous NC-DOT research (Gannon et al., 2016) in which zoysiagrass seeding was not recommended in low input situations on NC roadsides. But, using seeding is not without potential for failure. In this research, results ranged from seed failure to > 70% coverage in less than 5 months for the same plant timings. Late spring to early summer typically assured greater success in this study. Although establishment and coverage from sprigging material were not rapid, zoysiagrass sprigs were able to show comparatively similar coverage to seed plantings after about 12-15 months. Zoysiagrass even under roadside conditions were generally able to outcompete weeds and produced a near weed-free sward of zoysiagrass in ≤ 2 years. 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. Sprigging warm-season turfgrasses can be a great cost-savings 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. Results from the large-scale sprigging equipment tests indicate considerable differences exist among the individual and combined effects of the equipment and the sprigging timing on zoysiagrass establishment. Overall, greater zoysiagrass coverage was observed from sprigs applied in the fall compared to the spring. In non-irrigated roadsides, late spring and early summer months (May-July) generally have unfavorable climatic conditions (hot, dry) 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. 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 presented research suggested that the single greatest impact to zoysiagrass establishment may be limited water availability during the early phase of establishing and turfgrass growth. Comparison of experimental lines versus commercial cultivars identified there are genetic differences among zoysiagrasses for their ability to grow and thrive under the low input conditions found on roadside environments. While

there were differences in performance between locations and among years, in general Compadre performed the best among commercial cultivars and was the most stable across locations and years. Among breeding lines, XZ 14069 showed the most promise, surpassing Compadre's performance in several location × year combinations.

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INTRODUCTION

The Roadside Environmental Division of NCDOT has found zoysiagrasses to be a promising roadside vegetation, especially in harder to manage areas around median rails. The use of zoysiagrass may provide reduced long-term maintenance and improve associated aesthetics. Reduced maintenance can translate into increased safety due to a lower need for worker presence.

Zoysiagrass has been characterized for variation of many traits. These include winter-hardiness and high temperature tolerance (Beard, 1973), evapotranspiration rates (Green et al., 1991), response to drought (White et al., 1993), rooting (Marcum et al., (1995), salinity response (Quian et al., 1998), and insect responses (Reinert and Engelke, 1992). Based on favorable responses to many of these traits several zoysiagrass cultivars are commercially available throughout the transition zone and southeast US. Whether a particular cultivar will perform well in the transition zone is usually determined by its ability to persist through the coldest of winters. Common complaints with some of the older zoysiagrass cultivars were their slow establishment and recuperative rates. From an aesthetic perspective, a finer leaf blade and darker green genetic color are more desirable for landscape uses of turfgrasses.

Research to evaluate zoysiagrass sod establishment along guardrails was previously conducted for NCDOT by Gannon et al. (2017) with findings in (Report No. FHWANC/2013-17). In their study, the commercial cultivars 'El Toro', 'Meyer', and 'Zeon' were evaluated from sod strips. They found El Toro to be good at spreading from the vegetation piece in year 2 of their study; whereas, Meyer and Zeon spread at least 11% less. There was significant variability in establishment between the two years evaluated in this study. Their results suggested watering and other management inputs, in addition to environmental conditions and germplasm, could substantially influence success in establishing zoysiagrass. A failure due to inadequate water was pointed out by Gannon et al. to be the primary reason for failure in their attempt at seeding zoysiagrass on roadsides. A preliminary report from the University of Georgia (Clint Waltz, 2016, personal communication) indicated that their research found that October and November were the ideal months to seed zoysiagrass in central Georgia. Seeding during those two months reduced the time to 75% cover by 3 months compared to March and April seeding dates.

A number of zoysiagrass cultivars have been released on the market to address finer leaf texture and darker green color. In addition, a great deal of research has addressed freezing tolerance. While a rapid establishment rate is desirable, the limits of grow rate have not been fully evaluated since a rapid spread must be combined with strong aesthetic properties for a turfgrass to be accepted for landscape uses.

To date, little research has been performed regarding roadside use and management of zoysiagrass in North Carolina. For roadside use, the most desirable traits are rapid establishment and recuperative rates, dense canopy to suppress weed encroachment, tolerance to a variety of soils and nutritive situations, and freezing tolerance. A wide leaf blade (relative to other turf-type grasses) is acceptable. A longer internode length and larger node diameter may offer advantages

for roadside use compared to landscape uses. Turfgrass quality considerations are very different for roadsides compared to landscape uses.

The turfgrass breeding and genetics program at NCSU works on the development and selection of zoysiagrass breeding lines for improved cold hardiness, drought tolerance, turf quality and aggressiveness among other traits. A total of 81 accessions of our germplasm collection were evaluated for cold hardiness and aggressiveness during establishment in replicated trials at the Lake Wheeler Turfgrass Field Lab (Raleigh, NC) and the Lake Toxoway Country Club (Lake Toxoway, NC). The top 12 accessions were selected to be used as parents in crosses. Seventy nine plants were developed through controlled crosses in 2013. They were planted in the spring of 2014 in nurseries at Laurel Springs, Jackson Springs and Raleigh and evaluated on a monthly basis for coverage and turf quality during peak season. Additionally, entries were evaluated during the following spring for winter kill and green up. Means across locations were evaluated to identify top performers. However, coverage was selected as the unique variable considered for selection in this project. After visual inspection of the Lake Wheeler nursery, breeding lines XZ 14015, XZ 14069, XZ 14070, XZ 14071 and XZ 14072 were selected. These lines were moved to the greenhouse for propagation in order to generate enough vegetative material to establish replicated research plots at two different locations along roadsides.

The primary goal of this project is to find the best zoysiagrass cover for NC roadsides. To accomplish this goal, it must first be determined if sprigging new zoysiagrass germplasm will allow quicker establishment compared to currently available varieties. A preliminary objective for this project is to determine which zoysiagrass varieties are currently commercially available for consideration in this research. To accomplish this goal, the following tasks will be pursued:

1. Survey transition zone and southern states for commercially available zoysiagrass cultivars.
2. Compare breeding lines from the NCSU breeding program with promising commercially available zoysiagrass cultivars identified in Task 1.
3. Evaluate dormant and “in-season” sprigging and seeding trials to evaluate potential establishment methods that require lower inputs than sodding during periods of low-water requirements compared to more traditional establishment periods.

Outcomes from this project will provide DOT with guidelines for establishment of zoysiagrass on roadsides. Additionally, this research might identify zoysiagrass germplasm that is better adapted to roadside conditions than current commercially available cultivars. Results generated from this research will provide NCDOT with information so that they can select the best germplasm for reduced long-term maintenance and improved associated aesthetics. Reduced maintenance can translate into increased safety due to a lower need for worker presence.

CHAPTER 1: CULTIVAR SURVEY

Materials and Methods

To achieve the objectives of this task, the research team developed a two-pronged approach: In a first approach, University Extension Specialists were contacted in transition zone and southern states to gather information on the commercially available zoysiagrass cultivars in their state. Depending on the extent of information available from these individuals, a second approach was to make additional contact with sod producer organizations and/or sod producers. The goal was to determine the cultivars which are available and their relative success under that state's climatic conditions.

Findings and Conclusions

An email questionnaire was sent to surrounding states to identify zoysiagrass cultivars grown in their state. Initial contact was made with the primary Turfgrass Extension Specialist in each state. If the Specialist had the data readily available, they provided it. In many instances, the Specialist put us in contact with a representative of the state's "sod-growers association". In one instance, the representative contacted growers in their state and requested they respond to us directly. A summary table of cultivars sold in each state can be found in Table 1.

Table 1. A summary of cultivars reportedly grown in nine southern states.

Grass/State	AL	MS	GA	KY	NC	SC	TN	TX	VA
BK-7	X								
Carrizo								X	
Cavalier			X		X	X		X	
Compadre			X		X				X
Crowne					X			X	
Cutlass								X	
Diamond							X	X	
El Toro	X		X		X	X	X	X	
Emerald	X		X		X		X	X	
Empire	X	X	X		X	X		X	X
Geo	X		X		X	X	X	X	
Jamur	X	X	X		X	X		X	
L1F			X			X			
Leisure Time			X		X	X			
Meyer	X	X	X	X	X		X	X	X
Palisades		X	X			X	X	X	
Toccoa Green*								X	
Royal			X			X	X	X	
SoLo							X		

BA-189*								X	
Volunteer							X		
Y2								X	
Zenith			X	X	X	X		X	
Zeon	X		X		X	X	X	X	X
Zorro		X	X		X	X	X	X	
Total Number	**8**	**5**	**15**	**2**	**13**	**12**	**11**	**19**	**4**

*Toccoa Green = PristineFlora; BA-189 = UltimateFlora

Almost no states (including NC) report acreage of cultivars grown. As the person who annually polls NC sod growers, Dr. Grady Miller has found that most are very protective of that detail. When speaking with NC growers and a number of growers outside of NC, it is apparent that some sod farmers have substantial acreage of particular cultivars but may also maintain a small area of other lesser-sold cultivars. A few of the reasons for a majority of acreage in a particular cultivar include market demand, history of success, and growing ease. The lower acreage of the secondary cultivar may be due to it being a low-demand product, the requirement for royalty payment reducing margins, or a function of evaluating/expanding new grasses. Most growers are conservative when it comes to establishing new vegetative materials on their farm. Since it tends to be a long-term investment in space and resources, they may be reluctant to invest in a relatively unknown cultivar/grass.

Georgia and Texas reported the greatest number of cultivars grown in their states. Both states have climates well suited for zoysiagrass. The success of university breeding programs in both states may also contribute to their cultivar diversity. It should be noted that Texas reported growing five cultivars that were not available in any other state polled. States such as Virginia and Kentucky have traditionally concentrated on the production of cool-season grasses. Mississippi and Alabama likely produce a higher proportion of other warm-season grasses compared to zoysiagrass. For many years, zoysiagrass was touted more as a transitional zone warm-season grass. The release of improved cultivars in the last 25 years has probably led to a rapid increase in zoysiagrass popularity. There were few experimental zoysiagrasses tested in NTEP trials between 1990 and 2007, with entries averaging 20 grasses per trial. There was a significant increase in new germplasm tested beginning in 2013 (36 entries).

North Carolina is among the largest zoysiagrass producing states with a total of 13 cultivars reported to be grown. Recent annual sod surveys suggest there has been a growing demand for zoysiagrass and many of the state's sod growers have responded by diversifying inventory. A few of the cultivars are proprietary (e.g. Leisure Time) or only sold by one grower (e.g. Crowne); whereas several cultivars have widespread availability across the state (www.NCSOD.org).

Since this survey in early 2018, 'Innovation' and 'Prizm' are two new cultivars that are now available in NC and several other states. Other new zoysiagrasses known to be available in TX include: 'Trinity', 'Primo', and 'Lazer'. These zoysiagrasses are all targeting golf course markets, with these being introduced for use exclusively on golf greens.

CHAPTER 2: GERMPLASM COMPARISON

Materials and Methods

Five breeding lines, XZ 14015, XZ 14069, XZ 14070, XZ 14071 and XZ 14072, were selected for this study based on their aggressive growth habit. Each line was collected from the Lake Wheeler Turf Field Lab (Raleigh, NC) and propagated into twenty-four 0.25 x 0.50 m flats over winter 2017-2018 for sod establishment. Commercial cultivars Meyer, Zeon, Crown and Compadre were included as checks based on NC DOT's experience on the suitability of these cultivars for roadside conditions. Sod from these entries was obtained from commercial farms a day before planting. Additionally, Zenith (seeded) was also included as a control in order to compare the aggressiveness of breeding lines against a seed treatment. The day before planting, sod measuring 1.0 m × 0.46 m × 0.02 m (for cultivar checks) or 0.25 x 0.50 m (for breeding lines) was mechanically shredded (Model AZ-7H, Shred Pax Corporation, Wood Dale, IL), bagged in cotton, and placed in a temperature controlled room (22 °C).

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°06'43.2" N, 80°34'10.1" W) in the piedmont region (USDA zone 7a) was chosen as a western site. 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. Prior to planting, the testing areas were lightly disked (Compact Disc Model: 14-10-CD-YK, King Kutter Inc., Winfield, AL) to cultivate the soil and remove existing vegetation before planting.

The trials were established on 06/12/2018 and 06/13/2018 at Lenoir and Yadkin Counties, respectively. Both trials were set up as a randomized complete block design with three replications and plots measured 2.43 x 3.65 m with 0.61 m alleys in between. For planting, sprigs were broadcast by hand at a rate of 13 m^3 ha^{-1} and pressed into the soil with vertical coulter blades. For the seeded treatment, 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. Lastly, all plots were covered natural excelsior mat (Curlex CL Blankets, American Excelsior Company, Arlington, TX). Experimental units were fertilized and irrigated right after planting.

Trial establishment at the Lenoir testing site on June 12 2018.

Data collection started a month after planting and was conducted monthly during peak of season (June-October) at both locations 2018-2019. In 2020, due to coronavirus restrictions, data was collected only during peak of season and at the beginning of fall dormancy. Percent zoysiagrass cover was visually estimated on a 0 to 100% scale with 0 = no zoysiagrass cover and 100 = full zoysiagrass coverage. Additionally, data was collected on winterkill (on a scale of 1 to 9 where 9= no winter injury and 1= dead turf) in the spring, fall color (1-9 where 9= green turf, 1= completely brown turf) in the fall, turf quality (1-9 where 9= ideal turf, 1= dead turf and 6= minimal acceptable quality) at peak of season, and any disease presence as needed. 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. All interactions, except year × location were significant in the model. Therefore, results are present by separately year and by location.

Findings and Conclusions

Data collection in 2018 started in July and finished in November. Shortly after planting, volunteer vegetation occupied the majority of the plots as can be seen in the pictures below. However, data collection on percent cover values included zoysiagrass presence only. Thus, a 0% cover could still have weedy vegetation within the respective plot area. It was noted that infrequent mowing and increased zoysiagrass cover resulted in decreased presence of weed.

Weed presence at Lenoir county on July 31st (left) and Yadkin county on August 9th (right).

Percent zoysiagrass cover means by month of evaluation are presented for each location on the tables below. At Lenoir county, while seeded Zenith was significantly better than all other entries at the first evaluation, through months of evaluation Meyer and XZ 14069 surpassed it in speed of establishment. By years end, XZ 14069 was the top performing entry. Zenith, XZ 14070, and Compadre were also in the top performing group. At Yadkin county, initial growth was slower likely due to weed pressure. XZ 14069 was the top entry for the first three months of evaluation. However, coverage for all cultivars was not significantly different. In September, the second replication in this trial suffered herbicide damage during plot maintenance (alley spraying). Entry XZ 14069 suffered the most damage, losing approximately 15% of plot area. The loss affected the standing of this line for the October rating, but by the last rating in November it was the top performer along Compadre.

	Lenoir County									
Entry	**Jul-2018**		**Aug-2018**		**Sep-2018**		**Oct-2018**		**Nov-2018**	
Compadre	25.00	bc	33.33	ab	43.33	ab	53.33	ab	66.67	ab
Crowne	30.00	b	31.67	ab	35.00	bc	38.33	cde	50.00	cd
Meyer	28.33	b	40.00	a	46.67	a	55.00	ab	60.00	bc
Zenith	40.00	a	41.67	a	46.67	a	50.00	abc	68.33	ab
Zeon	9.33	e	15.00	d	21.67	d	28.33	de	56.67	bc
XZ14069	26.67	b	41.67	a	51.67	a	56.67	a	75.00	a
XZ14070	30.00	b	31.67	ab	46.67	a	53.33	ab	66.67	ab
XZ14071	16.67	cde	23.33	bcd	31.67	cd	41.67	bcd	51.67	cd
XZ14072	13.33	de	18.33	cd	25.00	cd	26.67	e	41.67	d
XZ9015	21.67	bcd	26.67	bc	31.67	cd	36.67	cde	58.33	bc
Means followed by the same letter are not significantly different at p=0.05										

	Yadkin County									
Entry	**Jul-2018**		**Aug-2018**		**Sep-2018**		**Oct-2018**		**Nov-2018**	
Compadre	25.00	abc	28.33	ab	35.00	ab	61.67	a	63.33	a
Crowne	25.00	abc	25.00	abc	30.00	abc	55.00	a	55.00	ab
Meyer	23.33	abc	23.33	bc	28.33	abc	41.67	a	45.00	ab
Zenith	26.67	ab	30.00	ab	41.67	a	50.00	a	55.00	ab
Zeon	10.00	d	11.67	c	15.00	c	35.00	a	35.00	b
XZ14069	35.00	a	38.33	a	45.00	a	55.00	a	63.33	a
XZ14070	20.00	bcd	21.67	bc	20.00	bc	35.00	a	36.67	b
XZ14071	18.33	bcd	16.67	bc	23.33	bc	35.00	a	38.33	ab
XZ14072	23.33	abc	25.00	abc	28.33	abc	41.67	a	45.00	ab
XZ9015	13.33	cd	13.33	c	18.33	bc	38.33	a	38.33	ab
Means followed by the same letter are not significantly different at p=0.05										

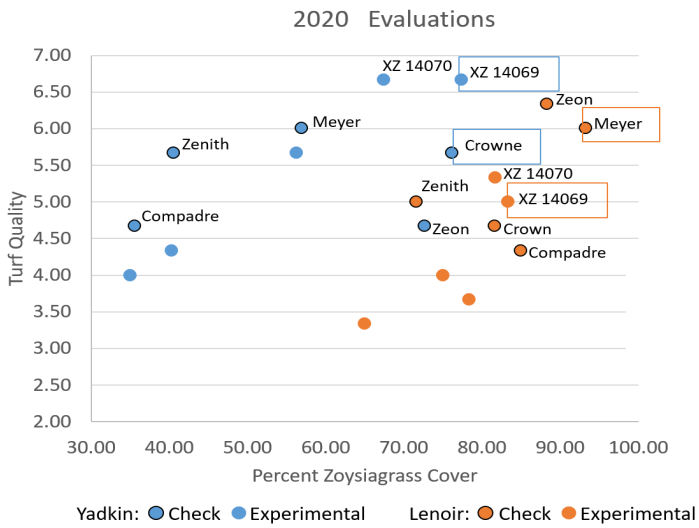
In 2019, winterkill on the plots at both locations was minimal and no significant loss of turf cover occurred. The table below shows means of monthly rating for percent zoysiagrass cover by location. At Lenoir County, entries XZ 14070 and XZ 14069 exhibited the highest coverage

throughout the year. Meyer and Compadre performed the best among cultivars and were not significantly different from the top two entries. It is important to highlight that at this location, performance of the seeded treatment, Zenith, fell during 2019 and this entry was one of the worst performers throughout the year. At Yadkin county, significant differences were observed among entries at the beginning of the year with cultivar Compadre exhibiting the highest coverage. By peak of season, XZ 14069 was the top performing entry followed by compadre. However, coverage of XZ 14069 declined during the fall due to fungal diseases. Compadre, Crown and Zeon exhibited the highest coverage by the last rating. XZ 14069 and XZ 14070 followed and while they were numerically lower, these differences were not significant.

	Lenoir County								Yadkin County							
Entry	**Jul-2019**		**Aug-2019**		**Sep-2019**		**Nov-2019**		**May-2019**		**Jul-2019**		**Aug-2019**		**Nov-2019**	
Compadre	71.67	abc	76.67	abc	80.00	ab	81.67	abc	80.00	a	73.33	a	80.00	a	86.67	a
Crowne	45.00	e	68.33	cd	73.33	b	78.33	abc	66.67	ab	63.33	a	71.67	a	88.33	a
Meyer	61.67	cde	75.00	abcd	75.00	ab	80.00	abc	36.67	bc	55.00	a	60.00	a	63.33	a
Zenith	63.33	bcd	65.00	d	66.67	b	68.33	c	48.33	abc	71.67	a	75.00	a	76.67	a
Zeon	58.33	cde	73.33	bcd	73.33	b	76.67	abc	48.33	abc	68.33	a	78.33	a	83.33	a
XZ14069	80.00	ab	80.00	ab	80.00	ab	85.00	ab	63.33	abc	76.67	a	83.33	a	80.00	a
XZ14070	81.67	a	85.00	a	90.00	a	91.67	a	45.00	bc	65.00	a	68.33	a	80.00	a
XZ14071	55.00	cde	70.00	bcd	66.67	b	75.00	bc	31.67	c	68.33	a	63.33	a	65.00	a
XZ14072	48.33	de	71.67	bcd	68.33	b	68.33	c	46.67	abc	53.33	a	58.33	a	60.00	a
XZ9015	55.00	cde	73.33	bcd	71.67	b	75.00	bc	41.67	bc	61.67	a	68.33	a	75.00	a
Means followed by the same letter are not significantly different at p=0.05																

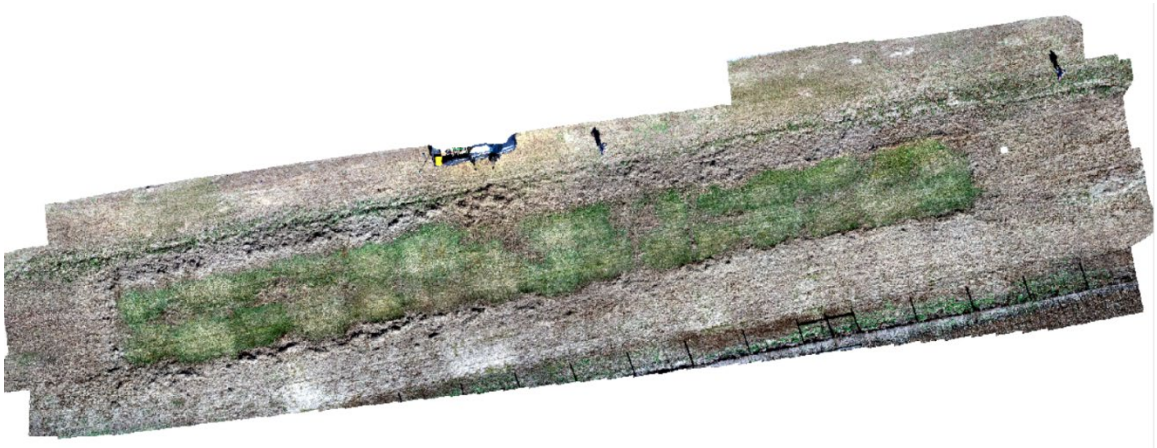
Plot cover on November 21st 2019 at Lenoir County (left) and November 11th 2019 at Yadkin County (right).

In 2020, due to research and travel restrictions caused by the COVID-19 pandemic, trials were evaluated with less frequency.



Plot of final % zoysiagrass cover versus turf quality by location. Markers for all checks are outlined in black while markers for breeding lines are not outlined. Boxes around names represent the top line and check in terms of aggressiveness at each location.

In conclusion, significant differences in speed of establishment were identified among the entries evaluated in this portion of the study. Furthermore, there are genetic differences among zoysiagrasses for their ability to grow and thrive under the low input conditions found on roadside environments. No significant advantage was observed for seeded versus sprigged materials. In fact, Zenith was one the lowest performers at the Lenoir County, the dry location, and was not among the top at Yadkin County, the wet location. Overall, we were successful at establishing and maintaining zoysiagrass on roadsides. As can be observed on the aerial image below of final zoysiagrass cover at the Yadkin county location, several of the plots show good ground cover a little over two years after planting. Some of our success in establishing these trials might be due to our ability to irrigate these plots immediately after planting. While there are differences in performance between locations and among years, in general Compadre performed the best among commercial cultivars and was the most stable across locations and years. Among breeding lines, XZ 14069 showed the most promise, surpassing Compadre's performance in several location × year combinations.



CHAPTER 3: ESTABLISHMENT TIMINGS

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. 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. Fewer germplasm entries were used in this portion of the study to maximize the establishment timings evaluated. 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 1). No irrigation was applied throughout this research.

Table 1. 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

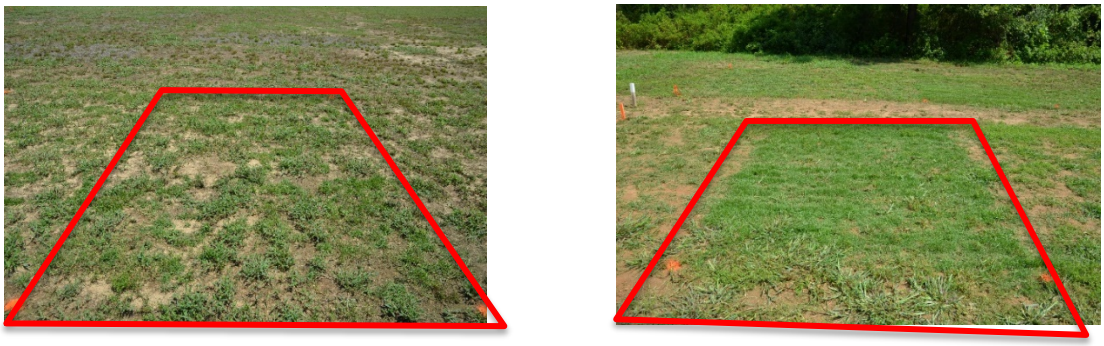
The treatment selection for zoysiagrass planting materials were made on the premises of a few things. The NCDOT has observed favorable sod establishment of Crowne under roadside conditions – promoting its selection. Compadre was chosen because it is commercially available as vegetative material and seed. 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.

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. Sprigs were made from sod removed from established plots at NC State University's Lake Wheeler Turf Field laboratory (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 mower (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. 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 year 2fall plantings. 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 NC 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.

Percent zoysiagrass cover was visually estimated on a 0 to 100% scale (0 = no zoysiagrass cover and 100 = full zoysiagrass coverage) monthly during the growing season (June – September). The visual representation of 0% cover could still have weedy 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.



Low zoysiagrass establishment percent (left) and high establishment percent (right) in the Yadkin County site.

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. 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.

Findings and Conclusions

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. 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. 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. Like the majority of eastern NC soils, the research location in Lenoir County is dominated by sand-sized particles (≥ 70%). Sand particles are relatively large, but have a low specific surface area, low water-holding capacity, and contribute very little to plant nutrition. 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. Data suggest 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 2). The rapid establishment via seed was not to be expected in a non-irrigated setting. Zoysiagrass seed planted in May was able to achieve 70% coverage only 11 WAP (Table 2). 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 2). Compadre sprigs established more readily from March April, May, and November plantings, ranging from 20 to 33% coverage when rated in August 2018 (Table 2). 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. 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 2). 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 2). 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 sprigging by September 2018 (Table 2).

Table 2. 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.

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 2). By June 2019, all monthly plantings of Compadre sprigs contained 70 to 80% coverage, with the exception of October. 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. 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. All year 1 plantings of zoysiagrass seed in Yadkin achieved 100% coverage by July 2019 (Table 2). 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 2). 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 at all monthly ratings compared to the remaining planting months. 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 3). 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 3). 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, 100% and 98%, respectively, than all other planting month × planting material treatments (Table 3). 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.

Table 3. 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 F	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.

Nearly total zoysiagrass coverage at Yadkin County site (May 12, 2020) by the end of the study.

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 4). 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. Seed planted in March and November showed the most initial coverage with 23% and 18% by August 2018, respectively (Table 4). 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 4). October planted seed had 39% coverage, which was the only other experimental unit to contain > 30% zoysiagrass coverage by July 2019.

Table 4. 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.

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 5). 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. 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 5).

Table 5. 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.

Poor zoysiagrass establishment in Lenoir County on June 9, 2020.

CHAPTER 4: ESTABLISHMENT METHODS

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. 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. 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.

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.

Traditional sprigger (left) and new sprigging unit (right). Note differences in sprig deposition in relation to soil surface between the two units. Both planted similar sprig rates.

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.

Equipment testing planting in Lenoir County on October 17, 2017 after cover materials were applied.

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. 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 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, 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.

Findings and Conclusions

Environmental Influence

Significant interactions with year and other factors occurred due to varying climatic conditions between years. 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 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 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 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.

In late September, 49 WAFP, sprigs applied via the new sprigging unit in Rowan County showed similar coverage, both with (31% coverage) and without (36%) post-sprig disking. At that same interval in Lenoir County, the old sprigging unit plantings had similar coverage (18%) 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% 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% cover without disking and 42% cover with disking (Table 4). At 90WAFP, applying the new sprigging unit in Rowan County provided the greatest regrowth from sprigs at 68% coverage

without disking, and 57% coverage with post-sprig disking. Conversely, in Lenoir County, the old sprigging unit provided 45% coverage and was no different than the new sprigger (with or without post-sprig disking) in Rowan County at 90 WAFP (Table 4).

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).

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% coverage) followed closely by the new sprigger with post sprig disking (just under 5%) (Table 5). In Lenoir County, all sprigging units produced ≤ 2.5% coverage 47 WAFP in year 2.

Resulting differences in coverage between the sprigging units in Lenoir and Yadkin County were likely due to the major soil differences between locations. 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). The depth of incorporation may have caused issues as others have found 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.

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% 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% coverage. By this time in Lenoir County, all sprigging units produced < 3% zoysiagrass coverage (Table 6).

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).

Spring Sprig Plantings

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).

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).

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. Reports in the literature 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. 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.

RECOMMENDATIONS

These recommendations are based on previous experience that indicates zoysiagrass is an excellent turfgrass species for use on NC Roadsides, with its greatest limitation perhaps being the ability to effectively (timely and economically) establish.

1. Research results from the establishment timing study suggested that seeding may be the most effective way to establish zoysiagrass on NC roadsides, although our experiences also demonstrated the limitations in zoysiagrass seed availability and reminded us that selection of seeded cultivars limits NC-DOT to only two cultivars (limits diversity for varied environments).
2. Vegetative establishment from sprigs is a viable option for zoysiagrass establishment, although it has many challenges.
    a. The primary challenge is soil water availability to sustain young sprigs. This research demonstrated that this is a more significant challenge when establishing zoysiagrass on sandy soil with low water holding capacity. Our recommendation is to concentrate most of the sprig planting in areas with "heavier soils" and perhaps seeding in areas with "sandier soils". More liberal use of post-planting watering should also be a consideration.
    b. The second challenge is achieving a quicker establishment. This may be offset with improved germplasm as well as by varied establishment techniques (using companion crops, sprigging equipment use, post-plant watering, etc). Our recommendation would be to continue to refine the sprigging equipment that was developed for this project along with evaluation of several companion crops planted with zoysiagrass.
3. Spring planting resulted in a faster establishment, but fall planting was still a viable option.
4. Germplasm evaluations in this study (compared to commercially available cultivars) showed that there is a strong case for continued evaluation of new germplasm. This project identified significant differences among zoysiagrasses for their ability to establish and thrive under the low input conditions found on roadside environments.

IMPLEMENTATION AND TECHNOLOGY TRANSFER PLAN

Findings from this research need to be expanded to 'operational-sized' roadside plots for further evaluation. To date, little 'operational-sized' research has been performed regarding roadside use and management of zoysiagrass in North Carolina. Additionally, while our results on establishment timings were conclusive, more research needs to be done on establishment methods that would improve sprig establishment such as the use of cover crops. A continuation project has been approved and is currently being implemented with the primary goal of evaluating the best zoysiagrasses for NC roadsides using large 'operation-size' plots. To accomplish this goal, larger roadside plots of seeded and vegetative zoysiagrasses will be established based upon results realized from research project 2018-02.

Promising experimental materials identified in research project 2018-02 will be transplanted in two pre-selected locations in NC. One seeded and one vegetative commercial cultivar will be planted alongside for comparison. The testing sites will need to be prepared for planting by NCDOT personnel by spraying out existing vegetation and tilled for seedbed preparation. The vegetative and seeded grasses will be established using equipment and techniques that would follow accepted NCDOT planting standards. Proposed sites selected to allow East and West sites to be planted in spring 2021 (Apr/May), fall 2021 Oct), spring 2022, fall 2022, and spring 2023 (minimum of 8 and potential total of 10 plantings – considering two planting sites- depending on weather conditions and suitable sites being available).

As a separate task, large areas of a sprigged zoysiagrass cultivar versus a seeded one will be planted in spring and fall to evaluate cover crops for both fall and spring plantings. These large areas will then be divided into blocks and individual cover crop treatments will be applied for a split plot design. Various cover crops such as Kobe and cowpea as warm-weather crops and wheat, oats, and winter pea as cool-season crops will be tested. As with Task 1, the planting locations will be selected based on the diverse climatic regions of NC will need to be prepared for planting by NCDOT personnel. The vegetative and seeded grasses will be established using equipment and techniques that would follow accepted NCDOT planting standards. Plots sizes will be determined based on available plant material.

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APPENDICES

Ben Gragg, Masters of Science graduate student in the Crop and Soil Science Department at NC State University, used this research as a thesis subject. His thesis titled, *Zoysiagrass (Z. japonica) Establishment Methods and Timings Evaluation and Comparison of Large-Scale Sprigging Equipment for Establishment of North Carolina Roadsides* was prepared in partial fulfillment of the requirements for his MS degree and it on file at the NC State University library. It can be downloaded at: https://repository.lib.ncsu.edu/handle/1840.20/38432