United States Department of Agriculture

**Progress Report**

| **Title:** | **Improving Drought Tolerance and Sustainability of Turfgrasses used in Southern Landscapes through the Integration of Breeding, Genetics, Physiology, Economics, and Outreach** |
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**Program Code:** SCRI **Program Name:** Specialty Crop Research Initiative


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**Non-Technical Summary**


The implementation of sustainable landscapes should be a goal in all regions of the country; however, severe droughts and limited water in the southern and western U.S. are dictating changes to the use of specific plant materials and irrigation in landscapes. There is a critical need for turfgrasses that provide functional surfaces tolerant to drought, reduced irrigation, and irrigation with reclaimed water. Failure to address these challenges will result in loss of turfgrass areas, along with their economic, environmental and social benefits. This transdisciplinary group from six universities was formed in 2010 to address these problems by developing turfgrasses with reduced irrigation requirements. To date, our group has released six improved cultivars for three of the most economically important turfgrass species grown in these regions. Significant opportunities remain to advance drought and salinity tolerant turfgrasses with innovations in genomics that leverage the successful economic impacts of our previous work with evolving industry needs and societal preferences. The levels of improvement of our released cultivars are promising and substantiate the need for continued quantification of their reduced water use. Implementing education and outreach efforts to increase their adoption will maximize the economic and environmental impact of these grasses. Advancing our successful research relationship will increase the efficiency of cultivar development through use of new screening tools and technologies, and dissemination of information to stakeholders and end-users. Ultimately, these efforts will facilitate our long-term goal of reducing water consumption in landscapes through the continued development and increased

utilization of drought tolerant turfgrasses.

**Accomplishments**

**Major goals of the project**

• Research in plant breeding, genetics, genomics, and other methods to improve crop characteristics: Approximately 58% of the effort, including:

1. Supply genotypes into a robust pipeline for multi-location evaluations in nurseries that differ in the type and intensity of abiotic and biotic stresses according to environmental conditions at each location to exploit genotype × environment (G × E) effects.
2. Evaluate advanced lines under long-term drought conditions and conduct ancillary trials for shade and salinity tolerance, pest responses, and sod-tensile strength.
3. Identify and validate quantitative trait loci associated with drought and salinity tolerance to implement marker-assisted selection.
4. Identify candidate genes through an integrated analysis that combines gene expression with metabolic information.
5. Generate high quality reference genomes for African bermudagrass, St. Augustinegrass, and zoysiagrass.

• New innovations and technology: Approximately 8% of effort, including:

1. Evaluate emerging UAS technologies for their potential to facilitate high-throughput phenotyping to improve data collection on drought tolerance associated traits.

• Efforts to improve production efficiency, productivity, and profitability over the long term: Approximately 34% of effort, including:

1. Quantify the water required to maintain acceptable quality in advanced lines generated from this program to develop water saving maintenance protocols for new cultivars.
2. Conduct surveys to evaluate trade-offs between drought tolerance and aesthetics.
3. Produce extension-outreach programs to help extension experts, stakeholders, and consumers understand the long-term impact of drought tolerant turf selection and conservation of water.

**What was accomplished under these goals?**

**(listed by objective and sub-objective number)**

1. The team including the industry advisory panel held an annual meeting at San Antonio, TX. Monthly teleconferences were held by sub-objective teams. Several project director and objective lead teleconferences were held for planning purposes. Several full team teleconferences were held to report on sub-objective progress.

2a. Top performing lines of bermudagrass, zoysiagrass, seashore paspalum, St. Augustinegrass (StAug) and corresponding check cultivars, were received from cooperators. Miller has coordinated the lyisimeter studies at three universities, providing a protocol for all to follow. Plant materials have been established in lysimters at NCSU, UF and TAMU. One preliminary run of water use research to quantify reduced water requirements has been collected at NCSU. Field plots of each species were established under a rainout shelter structure in Perkins, OK in 2020. Establishment rate and digital image analysis data was collected. Field plots were prepared at UGA, and plant materials were planted under a rain-out structure to establish for future minimum water requirements trial.

2b. Bermudagrass (OSU) and seashore paspalum (UGA) plant materials were received and propagated in the greenhouse for physiological experiments.

2c. A protocol for the Unmanned Aerial Systems (UAS) trials has been developed and a Zoom training was conducted (April 2020) for collaborators, which included faculty, undergraduate and graduate students. Additionally, a shared space for uploading images was set up so all collaborating institutions can put the UAS images in a single repository for future analysis. The initial pipeline for image processing has been set up, and initial UAS flights have successfully been conducted at UGA, OSU and NCSU.

3a. Breeding programs continue selection of parental lines and hybridizations to generate new hybrids.

3b. Breeders propagated and exchanged materials to establish nurseries: bermudagrass with 189 new lines (3 NCSU, 50 UGA-Tifton, 100 OSU, 16 UF, 20 UCR), seashore paspalum with 90 lines (all UGA-Griffin), StAug with 125 lines (50 NCSU, 45 UF, 30 TAMU) and zoysiagrass with 216 lines (47 NCSU, 10 UGA-Griffin, 50 UGA-Tifton, 70 TAMU, 39 UF). Nurseries were planted in late spring to early summer of 2020 at six locations for paspaulum and seven locations for all other grasses.

3c. Breeders propagated and exchanged materials to plant four replicated field trials in late spring to early summer:bermudagrass with 37 entries (1 NCSU, 8 UGA-Tifton, 20 OSU, 5 UF), Seashore Paspalum with 21 entries (all UGA-G), StAug with 30 entries (11 NCSU, 8 UF, 7 TAMU), and zoysiagrass with 45 entries (8 NCSU, 2 UGA-Griffin, 12 UGA-Tifton, 13 TAMU, 7 UF). All these trials were planted at eight locations (Riverside, CA; Jay and Citra, FL; Dallas, TX; Griffin, and Tifton, GA; Jackson Springs, NC and Stillwater, OK), except paspalum and StAug trials were not planted in NC and OK,

respectively. These trials will be used to evaluate long-term drought persistence. Additionally, ancillary trials to evaluate shade (bermudagrass at College Station, TX and Stillwater, OK; paspalum at Gainesville, FL and Griffin, GA; StAug at Raleigh, NC and Dallas, TX; and zoysiagrass at Gainesville, and Stillwater) and salinity (all four species at Riverside, CA) were established in summer 2020.
4a. At UGA, a previous seashore paspalum F2 population crossed between PI 509022 and HI33 consisted of 58 progeny. We split the marker dataset into markers that were heterozygous only in the female parent, those that were heterozygous only in the male parent, and those that were heterozygous in both parents to generate HA, AH and HH maps, respectively. The population was screened for variation in biomass (3 replicates), and leaf K+ and Na+ levels (1 replicate). However, because of the small population size, the phenotypic dataset was used only for training purposes. We also attempted to develop a new mapping population by crossing seashore paspalum accessions PI 299042 and HI10. All 94 progeny were analyzed with an SSR marker and proved to be selfs, suggesting that PI 299042 is self-compatible. At NCSU, a new mapping population of 147 F1 progeny was developed through crosses of previously identified lines segregating for drought tolerance. The population was planted at the Sandhills Research Station (Jackson Springs, NC) during summer 2020. A greenhouse trial containing 3 reps of the population will be conducted for additional phenotyping of drought related traits.
4b. At TAMU, we performed transcriptomic sequencing to identify differentially expressed genes in response to salt stress. Differential gene expression analysis was also performed between functional salt glands and non-functional salt glands in zoysiagrass. At UGA, preliminary trials in controlled environment conditions, to reproduce and confirm the improved drought tolerance seen in advanced field trials, have been initiated for bermudagrass and seashore paspalum; pots for StAug and zoysiagrass are being established.At NCSU, RNA-Seq was conducted using StAug lines (Raleigh and XSA 10098) with contrasting drought responses. Leaf and root tissues from drought treated and non-treated control treatments were used to extract RNA and constructed sequencing library. Raw data has been checked and processed to identify differentially expressed genes related to drought stress.
4c. At TAMU, we sequenced the Zoysia matrella genome using long read single-molecule real-time sequencing technology (PacBio) and assembled the sequences into 20 pseudo-chromosomes with assistance of combined information of high-density genetic map and high-resolution optical map (BioNano). To separate the two subgenomes, we developed a bioinformatics tool named "CISM-LTR". Although the two subgenomes are highly collinear, differential gene retention and preferential retention was observed in the two subgenomes. At NCSU, StAug cultivar Raleigh was sequenced and assembled to chromosome scale. Flow cytometry has been completed for samples targeted for genome sequencing to determine genome size. At UGA, we have been working with the Joint Genome Institute (JGI) to validate and improve seashore paspalum genome assembly v2.0, which was generated by JGI as part of a Community Sequencing Project led by James Schnable. The genetic maps generated under (1) as well as previously generated genetic maps (Qi et al. 2019) were aligned against assembly v2.0. Discrepancies between the maps and genome assembly are being used as guide to inspect and correct the assembly, leading to v3.0 which will be released once validation has been completed.
5a. At NCSU, Miller has updated one publication to include the new cultivars from the SCRI program. At TAMUS, turfgrass extension team (Drs. Segars and Bowling) have incorporated data and background information from the warm-season SCRI project into nearly every Extension presentation offered on Turfgrass Management over the past year. At OSU, a turf master gardener training slide set was updated in 2020 to provide the latest bermudagrass varietal information concerning Tahoma 31 and TifTuf bermudagrass for integration into Oklahoma and regional lawns. At UGA, we have hired to students to be involved in the project, undergraduate student worker (Copeland), and Graduate research assistance (Worley). Conducted "KeyPlayer" in turfgrass research, which will be completed in November of 2020. Members for both the Media Professional Steering Committee, and Turfgrass Specialist Steering committee have been identified.
5b. We completed survey questionnaires and are about to send a proposal to IRB.We expect to start the survey from November this year.
5c. Started survey of Atlanta area. Created an "eCognition" object based detection model, and labeled 6000 $m^2$ for deep learning model training. Started training for a "Raster Vision" deep learning model.

**What opportunities for training and professional development has the project provided?**

- TAMU: Training and professional development of Reagan Hejl (PhD student), Jose Diaz (MS student) at College Station TX postdoc (Haomin Lyu) in modern genomics and plant molecular biology techniques, postdoc in turfgrass breeding and high-throughput phenotyping (Tianyi Wang) at Dallas TX.
- OSU: Two graduate students have been trained to work in breeding and genomics research. Shuhao Yu works on this project and has planned to graduate in December, 2020. Alex Rodriguez works on the assessment of SCRI nurseries. Two MS students (Anmol Kajla and Alyssa Counce) have been trained in relationship to the greenhouse shade physiology studies. One Ph.D. student is currently working on this project for his dissertation work on social-economic analysis. Two MS student was trained and worked towards objective 2 (Charanpreet Kaur on rainout shelter and physiology and Ryan Earp on phenotyping/drone/UAS work). Six undergraduate students: Ms. Carly Godwin worked on this project and graduated in

December 2019. Mr. Colten Martin and Mr. Kellen King work on this project. Ms. Brooklyn Evan, Ms. Bailey Lockhart, Ms. Karli Fuss, and Ms. Claire Caldwell were all trained and worked on the field establishment and data collection towards objective 2. Post-docs researcher Lakshmy Gopinath, was hired and trained to work on all aspects of objective 2.

• UCR: The project has provided training in conducting field studies for our graduate student and information about advantages and possibilities of using warm-season turfgrass species for golf course superintendents and other professionals through virtual Field Day.

• UF: The project has provided training in conducting field studies for our graduate student and information about advantages and possibilities of using warm-season turfgrass species for golf course superintendents and other professionals through virtual Field Day.

• UGA: One graduate student has started in the Crop and Soil Science graduate program and has been training on experimental design, establishing plants for field trials and controlled environment trials, as well as techniques used in plant physiology. One graduate student received valuable training by assisting with experimental design and field layout, organization of plant materials and field plantings. Program technical staff and student workers also received similar training. Training of a MSc student, Thomas Gottilla (MSc student in Plant Breeding, Genetics and Genomics). Undergraduate student, and Graduate research assistant involved in KeyPlayer research and snowball sampling. Additionally, students were involved in the creation of posters, and symposium and conference presentations.

• NCSU: Postdoc Beatriz Tome Gouveia was hired to analyze breeding field and research data. MS student Greta Rockstad was trained to working on QTL mapping of drought tolerance and high-throughput phenotypic tools. Rotation Ph.D student Nico Lara was trained to collect morphological data from field trials. MS Student Cory Ketchum on water use and drought tolerance data collection training. Ph.D student Ashley Schoonmaker was trained to generate high-quality reference genome assemblies, perform linkage mapping and proper experimental design. In addition, multiple graduate students and research technicians were trained in the safe and proper use of UAV technology, best practices and proper workflows to operate and collect data using drone technology, process imagery in photogrammetry software, use GIS and image classification to summarize results, use programming languages such as R and python to view and process imagery.

**How have the results been disseminated to communities of interest?**

**Presentations**

1. Yu, Q. 2019. Turfgrass genomics: From genomics resources to molecular breeding. Department of Genetics and Biochemistry Fall Semester Seminar Series, Clemson University, Clemson, SC, Nov. 1.
2. Segars, C., and B. Bowling. 2020. Delivered a total of approximately 192 Extension presentations both live and using virtual platforms (Zoom, Teams, GoToWebinar). Primary audiences include Texas Turfgrass Professionals, Texas Master Gardeners, and homeowners.
3. Segars C., and B. Bowling. 2020. Offered approximately 8 training opportunities for AgriLife Extension personnel in an effort to further disseminate project findings.
4. B. Bowling. 2020. Introduced the warm-season SCRI to nearly 200 representatives of municipalities and water districts across Texas and gave a presentation on appropriate selection/watering practices to inform statewide municipal ordinances.
5. K.E. Kenworthy. 2019. CitraBlue St. Augustinegrass. Florida Turfgrass Assocation Annual Conference, August 13, 2019.
6. K.E. Kenworthy. 2019. Breeding Better Grasses for the Future. Palm Beach GCSA Symposium, September 26, 2019.
7. K.E. Kenworthy. 2020. CitraBlue St. Augustinegrass, A New Option For Landscapes. Florida Turfgrass Association Regional Seminars, January 7, 2020.
8. K.E. Kenworthy. 2020. CitraBlue St. Augustinegrass Availability and Other Breeding Updates. In Service Training for Country Agents, June 11, 2020.
9. K.E. Kenworthy. 2020. Research Impacting the Management of Florida Golf Courses. Everglade GCSA Symposium - July 14, 2020.
10. J. B. Unruh. 2019. Your $$ at Work: Research Impacting the Golf Industry, Palm Beach GCSA Symposium, September 26, 2019.
11. J. B. Unruh. 2020. Research Impacting the Management of Florida Golf Courses. Everglade GCSA Symposium - July 14, 2020.
12. Wu, Y.Q. 2019. Oklahoma State University turfgrass breeding program and cultivars update. 74th Annual Oklahoma Turfgrass Conference & Trade Show. Owasso, OK, November 19.
13. Wu, Y.Q. 2019. Update on the turfgrass breeding efforts at Oklahoma State University. Oklahoma Turfgrass Field Day, Sept. 25, OSU Botanic Garden.
14. Wu, Y.Q. 2019. Tahoma 31 bermudagrass: Drought resistance, cold hardiness, early spring green up, traffic tolerance, and high turf quality. Sports Turf Managers Association Conference, Phoenix, AZ, Jan. 25.
15. Yu, S., Y.Q. Wu, L. Yan, D. Martin, J.Q. Moss, C. Fontanier, T. Fang, and H. Dong. 2019. High density genetic linkage and QTL mapping in African bermudagrass. Oklahoma State University, Department of Plant and Soil Sciences Student

Research Symposium Poster Session.

16. Fontanier, C. 2019. Performance of bermudagrass and zoysiagrass in moderate to heavy shade. OSU Turfgrass Field Day. Stillwater, OK. Sept 26.
17. Fontanier, C., Q. Luo, S. Mitchell, B. Cheary, A. Kajla, S. Singh, N. Amgain. 2019. Connecting golf and STEM within horticulture and landscape architecture. Stillwater 5th Grade G&T Program. Stillwater, OK. Dec 19.
18. Copeland, E., Peake, J., Fuhrman, N., Schwartz, B. (2020) Updated: Improving drought tolerance and sustainability of turfgrasses used in southern landscapes through the integration of breeding, genetics, physiology, economics and outreach. Center for Undergraduate Research Opportunities. Athens, GA.
19. Copeland, E., Peake, J., Fuhrman, N., Schwartz, B. (2020) Improving drought tolerance and sustainability of turfgrasses used in southern landscapes through the integration of breeding, genetics, physiology, economics and outreach. presented at the College of Agricultural and Environmental Sciences Undergraduate Research Symposium. Athens, GA.
20. Schwartz, B., Worley, B., Peake, J., Fuhrman, N., (2020) Using Key-Player and Decision-Making Models to Increase Diffusion of Innovations in Turf. Crop and Soil Science Association Conference. Phoenix, AZ. Invited symposium speaker.
21. Copeland, E., Peake, J., Fuhrman, N., Schwartz, B. (2019) Improving drought tolerance and sustainability of turfgrasses used in southern landscapes through the integration of breeding, genetics, physiology, economics and outreach. Center for Undergraduate Research Opportunities. Athens, GA.
22. Miller, G. (2020) Drought tolerance in turfgrasses as part of a turfgrass management. Smithfield Regional Turfgrass Conference and Greensboro Regional Turfgrass Conference. February 26-27.
23. Greta Rockstad. Toward drought tolerant turf. Virtual talk on NC State 3-Minute Thesis Competition, September 2020

**Field days**

1. Wherley, B., B. Bowling, C. Segars and A. Chandra. 2019. Texas A&M Turfgrass and Landscape Field Day, College Station, TX. 150 attendees.
2. Dr. Bryan Unruh and Dr. Kevin Kenworthy spoke about water use and drought responses of turfgrass and our USDA funded research at the University of Florida Virtual Turfgrass Field Day, Oct. 14, 2020
3. OSU Turfgrass Field Day. Stillwater, OK. Sept 26, 2019.
4. OSU: Field tour with Jon Brown of Bethel Farms Sept 29, 2020.
5. 2020 UCR Turfgrass and Landscape Research Virtual Field Day (October 15, 2020).
6. NCSU 2020 Turfgrass Breeding and Genetics Virtual Field day. https://nctbg.wordpress.ncsu.edu/2020-virtual-field-day/
7. NCSU 2020 Turfgrass Virtual Field day. August 26, 2020.

**Social media**

1. The TAMU Extension Team has delivered Extension/outreach education through multiple platforms:
   - AggieTurf Website: https://aggieturf.tamu.edu - which also houses all Extension publications for the AggieTurf program.
   - AggieTurf Facebook Page: 2,633 Followers
   - AggieTurf Twitter: 1,877 Followers
   - Segars Twitter: 682 Followers
   - Bowling Twitter: 1,082 Followers
   - Constant Contact Email Listserv (~1600 subscribers)
2. Twitter: in addition to the project having its own account (https://twitter.com/SCRI_Turf) that is regularly used to communicate progress by the team and do outreach, many members of the team are active on Twitter. As a result, our project disseminates information on this platform to thousands of professionals in the turf industry.
3. UCR: Activities related to establishing trials were disseminated through Twitter and Videos.

**Other**

1. Drs. Bowling and Segars co-organized the 2020 Texas A&M Turfgrass Ecology and Management Short Course which includes professional training on appropriate turfgrass selection and key findings from the warm-season SCRI Project. The course is a 4-day intensive training. In 2020, there were approximately 32 attendees spanning the golf, landscape, sod production, and sports/recreation industry sectors.
2. Seven prospective sod producers were provided with consultation concerning available new bermudagrass and zoysiagrass varieties created by the multi-state project. Contact information of the licensing agents were provided to the prospective producers. Fifteen sports field managers at the high-school and university level were provided with consultation concerning fit of improved bermudagrass to their sports field situation. Three golf course superintendents received consultations by email and phone concerning sourcing new project bermudagrasses for their tees and fairways. One-hundred fifty-three consumers (150 emails, 3 phone calls) and 76 master gardeners (four turf master gardener sessions) received training on improved bermudagrasses and zoysiagrasses created by the project and the fit of these products in their

lawns/landscapes.

**What do you plan to do during the next reporting period to accomplish the goals?**

- **Objective 1:**
  - Continue organize summer and fall meetings (if Covid-19 restriction available) and monthly teleconferences.
- **Objective 2:**
  - UGA: Minimum water requirement trials will be initiated in 2021 in the rain-out shelter plots established in 2020 to determine the amount of water and potential water savings of advanced lines compared to commercial standards. Additionally, controlled environment trials will be initiated to better understand the mechanisms associated with improved drought performance. Potential mechanisms which will be explored include root morphology, water use, photosynthetic performance, and protective mechanisms such as the accumulation of compatible solutes or antioxidant enzymes.
  - NCSU: Next year we will conduct flights every two to three weeks over breeding plots. We will collect additional on-ground imagery for calibration and validation of UAV data and processing methods. We will continue to collect soil moisture and volumetric water content to help characterize seasonal changes in water availability at the site. We will develop additional tools and code to automate the processing and analysis of UAV-imagery for use in turf grass breeding programs. We will refine workflows and identify bottlenecks in UAV-based turf phenotyping. We will build relationships with collaborating universities to help guide analysis and standardize results.
- **Objective 3:**
  - UGA-Tifton: SSPN and RFT Field Trials. In the late fall of 2020, data will be collected from all field plots to document the level of grown in accomplished during this first season. Beginning spring of 2021, spring green up data will be collected from all field plots. Once grow in is complete for 90% + of plots, irrigation will be terminated, and we will begin to collect data on turf quality in the absence of irrigation.
  - UGA-Griffin: We will begin collecting data from the seashore paspalum shade trial in the spring of 2021 to document differential response of genotypes to shade in Griffin. Also in Griffin, we will increase plant materials and test entries by species using our greenhouse salinity testing protocols during the winter of 2020-21. We anticipate that two years will be required to complete salinity evaluations for all species.
  - TAMU: Initiate drought stress on the 2020 SSPNs and advanced trial for all four warm-season turfgrass species; continue data collection on the SSPN, advanced and shade trials.
  - OSU: The shade field trials will be evaluated in accordance with the project proposal and overall team discussions. Shade physiology studies are expected to conclude in spring 2021 with subsequent publication of results in late 2021.
  - UCR: Next year evaluation of turf quality, density, color and texture will be initiated in SSPN study. Irrigation with saline water will be applied between April and October 2021 in field salinity tolerance study. Restricted irrigation will be initiated in irrigation study at the beginning of dry season in 2021. Turf quality (during periods with and without stress) and leaf firing (during stress and recovery period) data will be collected in both studies.
  - NCSU: Initiate drought stress on all 2020 SSPNs and advanced trials. Continue data collection on the SSPN, advanced and shade trials.
- **Objective 4:**
  - UGA: We will conduct comparative RNASeq analysis of seashore paspalum accessions that vary significantly in their level of salt tolerance. Genes putatively contributing to the enhanced tolerance will be selected for further in-depth analysis. We will also conduct further analyses of a potassium transporter that is underlying a previously identified QTL for leaf $K^+$ in seashore paspalum.
  - UGA: Controlled environment trials will be performed in the selected top performing lines and standards. As part of these trials, tissue will be harvested for RNAseq and metabolomics to be used for identification of potential candidate genes and pathways.
  - TAMU: Publish the zoysiagrass genome and identify the major candidate genes associated with salt secretion in zoysiagrass.
  - NCSU: GBS will be conducted to genotype new mapping population and a linkage map will be produced. Field and greenhouse data will be taken on drought traits. Differentially expressed genes from RNA-Seq will be identified, annotated, and validated.
  - NCSU: We will finalize St. Augustinegrass reference genomes and perform annotation, complete the disease resistance RNA sequencing study in St. Augustingrass, sequence, assemble and annotate African Bermudagrass, sequence a set of parental lines used for generating triploids from African Bermudagrass.
- **Objective 5:**
  - UGA: We will meet with the Media Professionals and Turfgrass Professionals Steering Committees in February of 2021. Engaging Media and Turfgrass Professionals to identify communication channels and create media artifacts for different audiences: television spots, websites, social media, press releases, extension bulletins, etc. KeyPlayers that are currently

being identified will be utilized to maximize the impact of educational media and trainings to increase impact on the turfgrass network and subsequent strata of the network. Additionally, we will utilize, test, and refine the Decision-Making Model in Agricultural and Natural Resources to create a more efficient and reusable model for turfgrass professionals to increase impact on the turfgrass network and subsequent strata of the network.

• TAMU: Dr. Segars and Bowling have been working to create and update Extension resources to reflect project findings. Over the next year, they will complete the Zoysiagrass Lawn Management guide - which includes a section on cultivar selection - and will update the Texas Turfgrass Selection and Turfgrass Site Preparation and Planting guides to reflect the most current findings from the project.

• OSU:

• After the survey is done, the survey data will be analyzed to estimate consumer preferences and trade-off values among turfgrass attributes.

• Virtual turf field day will be held in 2021 to feature the new bermudagrasses and zoysiagrasses that have improved drought resistance. Linkage to commercial availability and purchase sources will also be included.

• A 2,000 sq. ft. demonstration lawn at the Oklahoma Gardening Studio grounds will be renovated from buffalograss to several of the new zoysiagrasses released from work of the past two SCRI warm-season grass development projects.

• A new filming segment/video will be made for the OK Gardening TV Show that features bermudagrasses and zoysiagrasses that have improved drought resistance and feature commercially availability.

• Consultations will continue with prospective sod producers concerning availability of production licenses of new SCRI warm-season grass products.

• Consultations will continue with sports field managers, golf course superintendents, turf managers and consumers concerning availability and fit of the newly commercialized warm-season turfgrasses with improved drought resistance.

**Participants**

**Actual FTE's for this Reporting Period**

| Role | Non-Students or faculty | Students with Staffing Roles | | | Computed Total by Role |
|---|---|---|---|---|---|
| | | Undergraduate | Graduate | Post-Doctorate | |
| Scientist | 5.1 | 1.5 | 12 | 3.2 | 21.8 |
| Professional | 2.3 | 0 | 0 | 0 | 2.3 |
| Technical | 2.5 | 8 | 0 | 0.7 | 11.2 |
| Administrative | 0.6 | 0 | 0 | 0.1 | 0.7 |
| Other | 0.5 | 0 | 0 | 0 | 0.5 |
| Computed Total | 11.0 | 9.5 | 12 | 4.0 | 36.5 |

**Student Count by Classification of Instructional Programs (CIP) Code**

| Undergraduate | Graduate | Post-Doctorate | CIP Code |
|---|---|---|---|
| 9 | 10 | 3 | 01.11 Plant Sciences. |
| | 1 | 1 | 45.06 Economics. |
| 1 | 1 | | 45.01 Social Sciences, General. |

**Target Audience**

Audiences communicated with include: municipal administrators, water management district personnel, sod producers, lawn maintenance professionals, landscape architects, golf course superintendents, sports turf managers, turfgrass scientists, county agents, master gardeners and home owners.

**Products**

**Accession No. 1020222** **Project No. NC09878**

| Type | Status | Year Published | NIFA Support Acknowledged |
|---|---|---|---|
| Conference Papers and | Published | 2019 | YES |

**Citation**

Yu, S.H., Y.Q. Wu, L.L. Yan, D.L. Martin, J.Q. Moss, C.H. Fontanier, T.L. Fang, and H.X. Dong. 2019. Genetic and QTL mapping in an African bermudagrass population. ASA-CSSA-SSSA International Annual Meeting. November 10-13, San Antonio, TX.

| Type | Status | Year Published | NIFA Support Acknowledged |
|---|---|---|---|
| Conference Papers and | Published | 2019 | YES |

**Citation**

Godwin, C., Y.Q. Wu, and T.L. Fang. 2019. Genetic identity and diversity among experimental and commercial cultivars of vegetatively propagated turf bermudagrass as assessed with SSR markers. ASA-CSSA-SSSA International Annual Meeting. November 10-13, San Antonio, TX.

| Type | Status | Year Published | NIFA Support Acknowledged |
|---|---|---|---|
| Conference Papers and | Published | 2019 | YES |

**Citation**

Yu, S.H., Y.Q. Wu, L.L. Yan, D.L. Martin, J.Q. Moss, and C.H. Fontanier. 2019. Genetic variability of spring greenup and drought response in interspecific hybrid bermudagrass selections. ASA-CSSA-SSSA International Annual Meeting. November 10-13, San Antonio, TX.

| Type | Status | Year Published | NIFA Support Acknowledged |
|---|---|---|---|
| Conference Papers and | Published | 2020 | YES |

**Citation**

Counce, A., C. Fontanier, B. Dunn. 2020. Effects of reduced R:FR ratio on turfgrass seedling growth. ASHS National Conference. August 10-13.

| Type | Status | Year Published | NIFA Support Acknowledged |
|---|---|---|---|
| Conference Papers and | Published | 2020 | YES |

**Citation**

Kajla, A., C. Fontanier, L. Zhang, and Y. Wu. 2020. Photosynthetic Response of Warm-Season Grasses Under Reduced Light Conditions. ASHS National Conference. August 10-13.

| Type | Status | Year Published | NIFA Support Acknowledged |
|---|---|---|---|
| Conference Papers and | Published | 2020 | YES |

**Citation**

Kajla, A., C. Fontanier, Y. Wu, and B. Schwartz. 2020. Persistence of Twenty-Four Bermudagrasses Subjected to Structural Shade. ASHS National Conference. August 10-13.

| Type | Status | Year Published | NIFA Support Acknowledged |
|---|---|---|---|
| Conference Papers and | Published | 2020 | YES |

**Citation**

Kajla, A., C. Fontanier, L. Zhang, Y. Wu, A. Chandra, B. Schwartz, and S. Milla-Lewis. 2020. Effect of low light conditions on photosynthetic parameters of selected warm-season turfgrasses. ASA-CSSA-SSSA Meetings.

**Accession No. 1020222** **Project No. NC09878**

| Type | Status | Year Published | NIFA Support Acknowledged |
|---|---|---|---|
| Conference Papers and | Published | 2019 | YES |

**Citation**

Gopinath, L., J.Q. Moss, and Y. Wu. 2019. Screening bermudagrass for freeze tolerance under controlled environment conditions. In 2019 Agronomy abstracts. ASA, Madison, WI.

| Type | Status | Year Published | NIFA Support Acknowledged |
|---|---|---|---|
| Conference Papers and | Published | 2019 | YES |

**Citation**

Gopinath, L., J.Q. Moss, and Y. Wu. 2019. Bermudagrass drought tolerance vs avoidance. In 2019 Agronomy abstracts. ASA, Madison, WI.

| Type | Status | Year Published | NIFA Support Acknowledged |
|---|---|---|---|
| Conference Papers and | Published | 2019 | YES |

**Citation**

Moss, J.Q., A. Ely, and Y. Wu. 2019. Drought response of seven common bermudagrass [Cynodon dactylon (L.) Pers.] selections. Southern Region of the American Society of Horticultural Science Annual Meetings, Birmingham, AL

| Type | Status | Year Published | NIFA Support Acknowledged |
|---|---|---|---|
| Conference Papers and | Accepted | 2020 | YES |

**Citation**

Schwartz, B., Worley, B., Peake, J., Fuhrman, N., (2020) Utilizing Key Players within Networks to Maximize Diffusion of innovations in Turfgrass Research. Poster presented at Crop and Soil Science Association Conference. Phoenix, AZ. Nov 10-13. Invited speaker for symposium

| Type | Status | Year Published | NIFA Support Acknowledged |
|---|---|---|---|
| Conference Papers and | Accepted | 2020 | YES |

**Citation**

Beatriz Tome Gouveia, Paul Raymer, Brian M. Schwartz, Kevin E. Kenworthy, J. Bryan Unruh, Charles Fontanier, Antonio C. M. Porto, Esteban F. Rios, and Susana R. Milla-Lewis. Performance and Genotype-by-Environment Interaction in seashore paspalum (Paspalum vaginatum) evaluated under shade conditions. CSSA 2020.

| Type | Status | Year Published | NIFA Support Acknowledged |
|---|---|---|---|
| Conference Papers and | Accepted | 2020 | YES |

**Citation**

Greta Rockstad. Evaluation of UAV-based imagery for drought stress traits in St. Augustinegrass. Poster on ASA-CSSA-SSSA virtual annual meeting, November 10-13 2020

| Type | Status | Year Published | NIFA Support Acknowledged |
|---|---|---|---|
| Journal Articles | Accepted | 2020 | YES |

**Citation**

M. Chavarria, B. Wherley, R. Jessup, and A. Chandra. 20XX. Physiological Responses to Salinity among Warm-Season Turfgrasses of Contrasting Salinity Tolerance. Accepted w/ Revisions Journal of Agronomy & Crop Science.

**Accession No. 1020222** **Project No. NC09878**

| Type | Status | Year Published | NIFA Support Acknowledged |
|---|---|---|---|
| Journal Articles | Published | 2020 | YES |

**Citation**

M. Chavarria, B. Wherley, R. Jessup, and A. Chandra. 2020. Leaf anatomical responses and chemical composition of warm-season turfgrasses to increasing salinity. Current Plant Biology 22: 100147 https://doi.org/10.1016/j.cpb.2020.100147

| Type | Status | Year Published | NIFA Support Acknowledged |
|---|---|---|---|
| Journal Articles | Published | 2019 | YES |

**Citation**

M. Chavarria, B. Wherley, A. Chandra, and P. Raymer. 2019. Salinity tolerance and recovery attributes in warm-season turfgrasses. HortScience 54:9: 1625-1631. https://doi.org/10.21273/HORTSCI13963-19

| Type | Status | Year Published | NIFA Support Acknowledged |
|---|---|---|---|
| Journal Articles | Awaiting Publication | 2020 | YES |

**Citation**

Xu, Yi, Jin Zhang, Jinping Zhao, Junqi Song, and Qingyi Yu. 2020. “An Improved Virus-Induced Gene Silencing (VIGS) System in Zoysiagrass.” In RNA-Based Technologies For Functional Genomics in Plants, edited by Guiliang Tang, Sachin Teotia, and Deepali Singh. Springer (in press).

| Type | Status | Year Published | NIFA Support Acknowledged |
|---|---|---|---|
| Journal Articles | Accepted | 2020 | YES |

**Citation**

Gouveia, B.T. G., E.F. Rios, J.A. Nunez, S. Gezan, P. Munoz, K. Kenworthy, J. Unruh, G. Miller, S. Milla-Lewis, B. Schwartz, P. Raymer, A. Chandra, B. Wherley, Y. Wu, D. Martin and J. Moss. 2020. Multi-Species Genotype-by-Environment Interaction for Turfgrass Quality in Five Turfgrass Breeding Programs in the Southeastern United States. Crop Science accepted with revisions.

| Type | Status | Year Published | NIFA Support Acknowledged |
|---|---|---|---|
| Journal Articles | Published | 2020 | YES |

**Citation**

Gouveia, B.T. G., E.F. Rios, J.A. Nunez, S. Gezan, P. Munoz, K. Kenworthy, J. Unruh, G. Miller, S. Milla-Lewis, B. Schwartz, P. Raymer, A. Chandra, B. Wherley, Y. Wu, D. Martin and J. Moss. 2020. Genotype-by-Environment Interaction for Turfgrass Quality in Bermudagrass Across the Southeastern United States. Crop Science. 2020;1-16. https://doi.org/10.1002/csc2.20260

| Type | Status | Year Published | NIFA Support Acknowledged |
|---|---|---|---|
| Journal Articles | Published | 2020 | YES |

**Citation**

Fang, T.L., H.X. Dong, S.H. Yu, J.Q. Moss, C.H. Fontanier, D.L. Martin, J. Fu, and Y.Q. Wu. 2020. Sequence-based genetic mapping of Cynodon dactylon Pers. reveals new insights into genome evolution in Poaceae. Communications Biology. DOI: 10.1038/s42003-020-1086-y

| Type | Status | Year Published | NIFA Support Acknowledged |
|---|---|---|---|
| Journal Articles | Accepted | 2020 | YES |

**Citation**

8. Ge, Candi, Chanjin Chung, Tracy A. Boyer, and Marco A. Palma. “Estimating Producers' Preferences for Turfgrass Attributes: A Combined Approach Using Discrete Choice Experiments and Eye-Tracking Technology.” HortScience, 2020

**Accession No. 1020222** **Project No. NC09878**

| Type | Status | Year Published | NIFA Support Acknowledged |
|---|---|---|---|
| Journal Articles | Published | 2019 | YES |

**Citation**

Qi P, Eudy D, Schnable JC, Schmutz J, Raymer PL, Devos KM (2019) High density genetic maps of seashore paspalum using genotyping-by-sequencing and their relationship to the Sorghum bicolor genome. Scientific Reports 9: 12183

| Type | Status | Year Published | NIFA Support Acknowledged |
|---|---|---|---|
| Journal Articles | Accepted | 2020 | YES |

**Citation**

Spiekerman JJ, Devos KM (2020) The halophyte seashore paspalum used adaxial leaf papillae for sodium sequestration. Plant Physiology (accepted)

| Type | Status | Year Published | NIFA Support Acknowledged |
|---|---|---|---|
| Journal Articles | Published | 2020 | YES |

**Citation**

Minor J, Campbell B, Waltz C, Berning J (2020) Water savings and return on investment of a new drought resistant turfgrass. J. Environ. Hort. 38:56-62

**Patent(s) and Plant Variety Protection(s)**

| Application Number | Application Filing Date | Title |
|---|---|---|
| US PP31695P3 | 04/21/2020 | Bermudagrass Plant Named OKC 1131 |

**Other Products**

**Product Type**

Educational Aids or Curricula

**Description**

• Undergraduate turf course: The use and application of UAV's for turf phenotyping was discussed during an afternoon 'Boot-Camp' to students in CS200 (Introduction to Turfgrass Management).

**Changes/Problems**

• TAMU: We were able to keep forward progress on the tasks of the project despite mandatory Covid-19 related shutdowns during spring/early summer 2019 at Texas A&M. A hiring freeze was also put into place by AgriLife Research, which put additional strains on our ability to staff the project. In March 2020, Dr. Bowling accepted a new position to serve as the Urban Water Extension Specialist at the Dallas Center. In this new role, she has started to establish new relationships with key water resource stakeholders in the state. She will maintain a foothold in water-efficient turfgrass management research and Extension.

• UF: Co-PI, Dr. John Erickson left the University of Florida. His projects were moved under the direction of Dr. Kevin Kenworthy. COVID-19 brought most face-to-face meetings and training events to a halt.

• OSU: COVID-19 caused delays in field operations in 2020. As a result, the SSPN nurseries were not fully grown in. It is expected that the nurseries will grow in by June, 2021. In the QTL mapping study at OSU, we changed to establish a field nursery from Goodwell, OK to Stillwater, OK due to the travel restrictions in summer 2020. Turfgrass Field Day was cancelled in 2020 due to COVID-19 issues. A replacement field day will be held in 2021 either virtually or in person to cover and feature the new varieties developed by the project. The 2020 Oklahoma Turfgrass Conference was altered in format and will not feature varietal information. This information will be provided in a virtual field day in 2021 as well as industry-specific webinars in 2021. On the socio-economics work, one of proposed objectives was to estimate potential economic impacts of

improved turfgrasses from past and current SCRI projects on economies of southern states. Due to low adoption rate of improved turfgrasses so far (except sports fields), we decided to modify this objective. The new objective is to examine effects of social networking on turfgrass professionals' new variety adoption. For this study, we will collect turfgrass professionals' virtual networking data via social media focusing on their social networking, new variety adoption, and socio-demographic information. Although this analysis will focus on turfgrass professional's new variety adoption, this study will also shed some light on effects of homeowners' social networking on their adoption of new turfgrass varieties.

• UGA: Many extension events normally held in person have been canceled, delayed, or moved to online formats due to COVID-19. One such example is the turfgrass field day, which is an important outreach activity that is in part used to promote the use of new cultivars to reduce water inputs. These disruptions may have potentially limited the audience reached by traditional extension activities. Identifying timelines for steering committees' meetings in the spring will pose challenges as turfgrass professionals face heavy time constraints in the spring of each year. It is likely that with COVID-19 limiting travel and time constraints that these committee meetings will be held virtually. One the genomics sub-objective, while we are attempting further crosses, it is possible that a crossability barrier exists between PI 299042 and HI10. We will analyze additional accessions for variation in leaf structure, including papilla size and salt tolerance that can be used as parents in crosses. In addition, we will explore conducting comparative RNAseq on accessions that differ in traits of interest.

• NCSU: COVID-19 caused delays in field operations in 2020. As a result, the SSPN and advanced trials were not fully grown in by the end of the season. The Raleigh x XSA10098 mapping population was planted late and we were not able to do any phenotyping this year. Our field day could not be held is person and was switched to an online format that limited the number of presentations that could be provided.

• UCR: Due to the problems and delay with hiring Lab assistant, resulting from Covid-19, postdoctoral scholar (Marta Pudzianowska) took over most of the technical responsibilities (propagation and maintenance of plant material, planting and maintenance in the field) with help of other members of the team.

• USDA-ARS: Due to conronavirus affecting labs, scaffolding to generate pseudomolecules had to be changed from completion with BioNano technology to scaffolding with linkage maps for St. Augustinegrass. Savings from this effort will allow for sequencing a second St. Augustinegrass which is included in the disease resistance study.