

2021 NIFA Report of Accomplishments Executive Summary

Overview

This report reflects the accomplishments of Research and Extension programs from the College of Agriculture and Life Sciences (CALs) at North Carolina State University (NC State). Our portfolios of cutting-edge, solution-driven research is extended to all North Carolinians through NC Cooperative Extension, helping them transform science into everyday solutions that improve their lives and grow our state.

Despite disruptions caused by the COVID-19 pandemic that continued into 2021, research and Extension faculty and staff in CALs stayed committed to providing solutions to the problems facing our state and nation. While navigating ever-changing COVID-19 protocols to protect the safety of the campus community and the public, CALs professionals continued working to transform science into everyday solutions that improve lives and grow our state. The North Carolina Agricultural Research Service (NCARS) and NC State Extension prioritized efforts aimed at solving the complex challenges facing food and agriculture.

Our extensive partnerships with business, industry and government generate a unique culture of interdisciplinary collaboration to address global challenges by merging creative, innovative ideas with purposeful action. The Plant Sciences Initiative is one such example. Through the initiative, CALs researchers and Extension professionals are collaborating with researchers from across NC State, industry, and every level of government bringing together the brightest minds in academia, government and industry to drive vital research and innovation. Initially envisioned by farmers, N.C. PSI utilizes an interdisciplinary approach to solving agricultural challenges, pairing experts from agriculture and life sciences with those from engineering, chemistry, and many other disciplines with the shared goal of addressing tomorrow's agricultural concerns today. In 2022, NC State cut the ribbon on the NC State University Plant Sciences Building - a cutting edge facility designed specifically to facilitate collaboration and creativity from issue identification through every step of research and development. NC State has also assembled the resources, partners and skilled personnel to shape growth in the food-animal industry. CALs and the College of Veterinary Medicine are partnering with industry leaders to bringing interdisciplinary sciences together to solve grand challenges and bring new ideas to market faster through a new North Carolina Food Animal Initiative. Through this initiative, NC State University is working to improve productivity, profitability and sustainability of industries in agriculture and the life sciences while helping North Carolina become the world leader in food-animal sciences.

Extension agents statewide serve as the conduit through which the needs of the community are communicated to the University. Local agents identify local challenges, present these opportunities to Extension specialists and faculty researchers who then conduct the research and find solutions. These specialists and researchers then train Extension agents in science-backed best practices to address the concerns. Through programs, training events, and hands on support, Extension agents deliver this essential information into the hands of the growers, industry, and members of the community. The cycle continues as new challenges arise, and NC State is poised to develop innovative solutions to meet the needs of our communities both here in N.C. and beyond.

Critical Issues

Improving Plant and Animal Agriculture Systems. Agriculture and agribusiness – food, fiber, and forestry – account for one-sixth or \$92.7 billion of the state's income. In the crops area, NC State researchers in the College of Agriculture and Life Sciences (CALs) conducted genetic research, developed new varieties, and developed new technologies and practices to increase production. Researchers applied cutting-edge genetic approaches that support more efficient development of new varieties with characteristics such as drought, disease and insect resistances allowing for

reduced use of pesticides and fertilizers. NC State Extension agents and specialists provided a combination of virtual and limited size in-person field days and grower meetings to share the research and best management practices coming from the innovative work conducted by CALS scientists. Extension expanded its use of technology to deliver real time pest, disease, weather, and new technological and practice updates to growers during a time of COVID-19 restrictions and to keep growers informed about the latest developments. The use of social media, websites, educational videos, webinars, and online learning modules was expanded to reach remote audiences. Extension even started a podcast series, Crop Sense, featuring 20-minute segments with extension specialists that provide key information about crop production, profitability, and environmental sustainability. Horticulture agents provided additional programming to homeowners due to an increased interest in gardening stemming from families spending more time at home and food shortages due to supply chain disruptions.

In the area of animal agriculture, research and extension worked to support an industry that accounts for 70% of North Carolina's agricultural income and jobs. In response to public demand for antibiotic-free production, CALS researchers tested the effects of dietary interventions on the intestinal health and growth of nursery pigs without the use of antimicrobial growth promoters. Similarly, poultry researchers worked on developing new ways to naturally enhance poultry gut bacteria to defend against antibiotic resistant germs. NC State researchers are also conducting research to determine the environmental and management factors that influence the longevity and fertility of honey bee queens, since queen problems are one of the major triggers of honey bee colony losses. NC State Extension specialists and agents delivered information on innovative products, technology, and best management practices developed through research conducted at NC State to producers using in-person and virtual workshops, certification programs, webinars, factsheets, and newsletters. Extension also led the creation of new disease and waste management plans, conducted on-site sludge surveys and equipment calibrations, and developed novel technologies to enhance animal health. Educational opportunities provided producers with knowledge of research-based best management practices spanning general animal husbandry, animal health, and disease management, waste management, poultry processing, and value-added marketing channels for calf sales including the use of electronic identification (EID) tags, co-mingled truckload lots, and quality assurance evaluations.

Protecting Environmental and Natural Resources. NC State College of Agriculture and Life Sciences developed and promoted research-based natural resource stewardship, and climate-smart agricultural and forestry best management practices to sustain the quality and diversity of North Carolina's natural resources, conserve and protect the environment, boost sustainable energy, and mitigate climate change. Researchers and extension specialists partnered with the NC State Climate Office to develop a tool to provide key data to pesticide applicators so they can carefully time their applications and minimize pesticide drift. In addition, pesticide training programs helped applicators meet requirements to maintain their licenses. To minimize environmental harm from animal agricultural operations, extension agents and specialists provided thousands of animal waste operators with training and education enabling them to maintain required permits, implement best management practices, and avoid fines. In addition, researchers studied the effect of poultry litter application on crop yields and quality. NC State research and extension efforts also focused on protecting the quality of water supplies within the state. CALS researchers analyzed geospatial data to evaluate septic system vulnerabilities. The data is being used in extension activities to inform the public in coastal communities about septic systems, water quality, and human health. Extension specialists also helped protect water quality by installing sites for demonstrating best management practices, leading streambank repair projects, monitoring water contamination, developing stormwater plans, and educating thousands of wastewater operators, erosion control professionals, environmental health specialists, septic system installers, engineers, soil scientists and others.

Enriching Youth, Family and Community Well-Being. NC State extension professionals found creative ways to enrich youth, family and community well-being. Extension provided resources to help parents and guardians promote healthy relationships, utilize positive parenting practices, and

manage stress. Extension staff conducted counseling sessions to assist senior citizens with choosing Medicare Part D prescription drug plans. To support workforce development, NC State Extension provided education, guidance, and specialized training to entrepreneurs, program staff and interns, and minority owned business. Extension conducted outreach to lay critical groundwork to strengthen NC's economy while fostering healthy, engaged communities in which individuals from all backgrounds can thrive. Extension played a critical role in rolling out the North Carolina Department of Health and Human Services (NCHHS)'s plan to reach every farm in the state with COVID-19 response resources, including educational materials, masks, sanitizer, and vaccinations. NC State Extension participated in COVID-19 task forces across the state's farming governmental and nonprofit agencies to coordinate additional support for farmworkers.

To help youth develop life skills that will prepare them for future success, NC State Extension provided 4-H Youth Development programs that focused on civic engagement, healthy living, and STEM. In 2021 Extension offered a broad range of in-person and virtual 4-H educational programming. Activities included day camps and overnight camps; clubs; hands-on learning activities in the home, classroom, and community; online educational programs with video lessons and supplementary written materials; and interactive activity kits for children to enjoy during stay-at-home restrictions. 4-H used creative approaches to engage youth who were feeling the effects limited in-person learning and extracurricular activities by providing opportunities for hands-on activities. 4-H partnered with community organizations to provide pop-up STEM activities, created educational activity kits, camp-in-a-box kits, field days with small stations, and mini camps. 4-H also provided activities that focused on stress reduction and mindfulness to help with increased youth mental health issues arising from the ongoing pandemic.

Enhancing Food Safety, Nutrition and Health. Through research and extension efforts, NC State's College of Agriculture and Life Sciences not only developed novel approaches to producing healthier food and helped protect the safety of food across the entire supply chain but also encouraged consumption of healthy foods. As part of a multi-state research team to enhance food safety, researchers developed devices to deliver in-package sanitation of fresh packaged produce such as baby spinach, tomatoes, and mushrooms. Extension delivered training based on university-based research in produce safety (FSMA), acidified foods manufacturing, good manufacturing practices (GMP), hazard analysis and critical control points (HACCP), certified food protection manager (NC SafePlates), and home food preservation. NC State also led the formation of a multistate project team, FoodCoVNET, to fill a gap in research-based information that became visible as public health and regulatory officials scrambled to provide guidance for the food sector to address the emerging SARS-CoV-2 pathogen based on scarce data.

To enhance the supply of fermented dairy products and promote human health and nutrition, NC State researchers are developing and deploying technologies based on CRISPR, a family of DNA sequences found in bacteria and similar organisms. NC State's patents and expertise have been deployed commercially in fermented dairy products and the CRISPR genome editing technologies are also being deployed in crops, livestock, and even trees to breed a more sustainable, resilient food supply chain. To promote health and wellness, prevent chronic disease, and increase access to healthy foods, NC State Extension used a combination of research-based direct educational programs and policy, systems and environmental change efforts to help families and communities reduce barriers and implement behavioral changes. As a result of NC State Extension programs, 22,009 adults increased their fruit and vegetable consumption, 7,279 increased their physical activity, and 7,720 consumed less sodium in their diet. To reduce food insecurity and increase protein sources available at food banks, extension agents partnered with other nonprofits, food banks, hunter groups, and food processors to create a system for increasing the amount of venison donated to food banks. Extension also worked with farmers markets to establish donation stations for customers to donate produce for distribution to local food pantries.

Stakeholder Input

Methods to Collect Stakeholder Input

The NC State College of Agriculture and Life Sciences (CALs) Compass 2030 strategic planning process, which kicked off in spring 2021, is well underway and making great progress towards the creation of our new strategic plan that will chart the course for CALs through the year 2030. We use our strategic plan to guide and direct the college as we pursue exceptional learning and working spaces, innovative research, deliver exceptional teaching, and determine the most impactful ways to connect with the community via Extension. We have specifically designed this process to be stakeholder-driven to ensure the plan is a reflection of everyone within, or touched by, the CALs community. Over the past year the planning team, which includes faculty and staff representation from across the college, has engaged internal and external stakeholders in the strategic planning process through a series of surveys, interviews, small-group meetings, focus groups, and larger listening sessions. These avenues provided for our faculty, staff, and student groups; university and college leaders, including department heads and various other unit leaders; and external stakeholders across the state to have an opportunity to make their voices heard. NC State Extension is also creating a cascaded strategic planning process that is underway drawing from key themes identified in the CALs process and further exploring the Extension related themes with stakeholder groups through interviews, focus groups, listening sessions, and surveys.

How Stakeholder Input is Used

Stakeholder input was used to set research agendas and extension program priorities by identifying emerging issues and relevant community needs. In 2021, stakeholder input surrounding the needs resulting from the COVID-19 pandemic guided operational, research and programmatic functioning. On the operational side, stakeholder input influenced how and where programs were delivered and the method of program delivery including the use of virtual and reduced size group programs. Some research efforts shifted to study COVID-19, farmworker safety, food safety, vaccinations, and other related topics based on stakeholder needs. Extension programming also shifted to address stakeholder identified needs including food insecurity, mask and vaccination distribution efforts, school closures, wellness and stress caused by isolation, financial hardships, food preparation, and other community needs.

Highlighted Results by Project or Program – Impact Statements

Enhancing Food Safety, Nutrition and Health

Implementation of CRISPR-based technologies in food bacteria - Rodolphe Barrangou

ENHANCED FOOD SUPPLY CHAIN RESILIENCE THROUGH CRISPR TECHNOLOGIES: Bacteria play diverse roles in the food supply chain. NC State develops and deploys technologies based on CRISPR, a family of DNA sequences found in bacteria and similar organisms. NC State's patents and expertise have been deployed commercially to enhance the supply of fermented dairy products and promote human health and nutrition. NC State's genome editing technologies are also being deployed in crops, livestock, and even trees to breed a more sustainable, resilient food supply chain. Researchers have published 20 manuscripts, given over 50 talks and technical presentations at seminars and scientific conferences, collaborated with start-up companies and industrial partners, and expanded the training of scientists in food production, biotech, and agriculture. These results exemplify the progress being made through the North Carolina Plant Sciences initiative; a major interdisciplinary effort designed to address the biggest challenges facing agriculture today.

Engineering for food safety and quality - Deepti Salvi

IMPROVED PRODUCE SANITATION APPROACHES: Consumers expect the US food industry to develop sustainable, safe, high-quality nutritious food products. NC State researchers have begun to tackle these challenges by collaborating with other universities in a multistate research project using innovative technologies that are more sustainable and chemical residue free. The researchers are using cold plasma, the fourth state of matter, which can be generated by passing electricity through air, for various applications. Novel cold plasma devices were developed to deliver in-package sanitation of fresh produce such as baby spinach, tomatoes, and mushrooms, and plasma-activated mist was used as a novel strategy for fresh produce sanitation. Protein-based surrogates and machine learning strategies were used to analyze the efficiency of plasma-based sanitation approaches. In addition, researchers demonstrated the use of plasma-treated solution to enhance the growth and yield of hydroponic basil. Cold plasma applications in food and agriculture can improve food safety, enhance plant growth, and reduce water, energy, and space usage. With this new technology, rather than putting produce in a plastic bag at the grocery store, it could come pre-treated with plasma to prevent the growth of harmful bacteria, then packaged in a sealed, recyclable container. Results have been presented at local and international conferences and seminars and submitted to peer-reviewed journals. These results lay a critical groundwork for enhancing food safety, quality, and nutrition while addressing the issues of food waste and environmentally harmful packaging. This demonstrates how NC State is growing solutions, protecting the environment, and serving all North Carolinians.

Protein-polyphenol colloidal aggregate particles for food structure and health functionality – Mary Ann Lila

IMPROVING THE FLAVOR AND TEXTURE OF ENRICHED FOODS: Despite their well-publicized health benefits, consumers often avoid consuming fruits, vegetables, and other plant-based foods that contain a high concentration of polyphenols, micronutrients that naturally occur in plants. This is in part because such plant-based foods can have an undesirable taste, they are highly perishable, and they can be inconvenient to prepare. In addition, many consumers avoid protein-enriched processed foods due to dislike of their tastes and textures. To address this challenge, NC State's Lilalab has developed a simple strategy to bind fruit and vegetable nutrients with edible proteins to create a concentrated, versatile ingredient that can be incorporated into foods to enrich their nutritional value while providing a pleasing flavor and texture. Researchers at the Lilalab have already demonstrated the ability of this technique to combat a major industry problem with high-protein snack texture and to enhance the bioavailability of key plant-derived nutrients in enriched foods, and high-protein, low-sugar gummies have been created and used in a targeted clinical trial. Enhancing the consumer appeal of nutrient-dense enriched foods is just part of how we are feeding our future and improving our health.

Food safety – Extension Program**ENHANCED FOOD SAFETY THROUGH INFORMATION, RESOURCES AND PROGRAMMING TO PREVENT**

FOOD SAFETY HAZARDS: Despite food safety communication efforts by many sectors, foodborne illness remains a significant health issue in North Carolina and across the U.S. NC State Extension utilized various methods to enhance food safety throughout the supply chain through producer and consumer-based information, resources and programming aimed at preventing food safety hazards. NC State Extension provided technical assistance to food businesses to ensure the safe development and production, packaging, and distribution of food products for human consumption. Extension also provided training to food service employees and managers to ensure safe handling of food at retail establishments and prevent outbreaks of foodborne illness. Extension's efforts also reduced the incidence of foodborne illness in the home through the transfer of research-informed best practices to consumers on home food preparation, storage, preservation, canning, fermenting, and other topics relevant to families. NC State Extension's extensive statewide network of county-based agents and campus specialists provided businesses and families with trusted research-based knowledge to prevent foodborne illness.

Nutrition and health – Extension Program**EVIDENCE-BASED PROGRAMMING TO EMPOWER NORTH CAROLINIANS TO ADOPT HEALTHIER**

LIFESTYLES: Chronic diseases such as cancer, heart disease, stroke, and diabetes are among the leading causes of death. Through a healthy diet and physical activity, many of these chronic conditions are preventable. NC State Extension provides direct nutrition education and promotes policies, systems and environments to support health and wellness, prevent chronic disease, and increase access to healthy foods. Extension utilized multiple methods and empowered individuals and families to implement behavioral changes focused on healthy eating patterns and physical activity to improve overall health and to use learned strategies, skills, and resources to reduce the risk of chronic disease and illness. As a result of NC State Extension programs, 22,009 adults increased their fruit and vegetable consumption, 7,279 increased their physical activity, and 7,720 consumed less sodium in their diet. NC State Extension provided evidence-based information to empower North Carolinians to adopt healthier lifestyles.

Enriching Youth, Family & Community Well-Being**Improving pest management in urban ecosystems through comprehensive integrated pest management plans - Sydney Crawley**

INTEGRATED PEST MANAGEMENT IN URBAN ENVIRONMENTS: Integrated pest management (IPM) programs more effectively control pests by integrating an array of pest management methods rather than relying on pesticide-only approaches. NC State researchers evaluated 3 novel products developed by chemical companies and assessed their potential for inclusion in urban structure IPM strategies for ants and rodents. In addition, NC State researchers partnered with Banfield Bio to develop and evaluate a novel trap that captures ticks on their backs and published the results in a peer-reviewed entomology journal. Banfield Bio is currently attempting to commercialize the "Yans" tick trap. With commercialization and widespread use, this device can help municipalities make more informed decisions about pesticide use for tick management, reducing the impact of pesticides across large areas of land in the US. NC State's integrated research and extension IPM program in urban environments is reducing the number of urban pests in structures, mitigating excessive pesticide input and improving human and animal safety, and reducing the development of insecticide resistance in urban pests.

4-H youth development – Extension Program

4-H PROGRAMS PROVIDE OPPORTUNITIES FOR ALL YOUTH TO IDENTIFY THEIR PASSION OR "SPARK" AND DEVELOP LIFE SKILLS TO BE PREPARED FOR FUTURE SUCCESS: NC State Extension's 4-H Youth Development program focuses on positive youth development, by providing safe experiences that increase the likelihood of enhanced wellbeing and optimal development for participating youth. To enhance the well-being and development of youth, Extension provides opportunities for all youth, ages 5-18, to identify their passions or "Sparks" and develop life skills that prepare them for future success. NC State Extension provided 4-H Youth Development programs focused on civic engagement, healthy living, and STEM. In 2021, Extension offered a broad range of in-person and virtual 4-H educational programming. Activities included day and overnight camps, clubs, hands-on learning activities (or interactive kits) that could be completed in the home, classroom, or community, and online educational programs with video lessons. Even with the challenges of being in the midst of a pandemic, 4-H continued to empower youth to reach their full potential by providing opportunities for "Learning by Doing".

Families and communities – Extension Program

USE OF PARENTING, CAREGIVING AND LIFE SKILLS TO CREATE STABLE, SAFE AND SECURE ENVIRONMENTS: Individuals and families in North Carolina face challenges to overall well-being. To support individuals and families, NC State Extension developed and used educational programs, websites, social media, newsletters, and other methods to increase the knowledge and skills of individuals and families. As a result of Extension programs, more North Carolinians use new strategies to cope with stress; practice self-care, mindfulness, and gratitude; and lead lives that balance physical, mental, and emotional health. North Carolina caregivers at all stages of life are now using effective parenting skills to create stable, safe, and secure environments because of participating in NC State's Extension programs. The knowledge gained from NC State Extension's workshops and technical assistance on financial management not only led to an improvement in the financial condition of the individual participants but resulted in a ripple effect felt throughout the economy.

Economic development – Extension Program

BUILDING LOCAL ECONOMIES AND HELPING COMMUNITIES BECOME ATTRACTIVE PLACES TO LIVE, WORK, AND PLAY: The well-being of North Carolinians is determined in a large part by local economies. Vibrant local economies have an engaged workforce with a sense of opportunity, thriving downtowns with many local businesses, and high-quality economic development planning that builds on local assets. To support workforce development, NC State Extension provided education, guidance, and specialized training to entrepreneurs, program staff and interns, and minority owned business. Extension conducted outreach to lay critical groundwork to strengthen NC's economy while fostering healthy, engaged communities in which individuals from all backgrounds thrive.

Community development – Extension Program

LEADERSHIP DEVELOPMENT AND PARTNERSHIP BUILDING: North Carolina's community well-being is built on a foundation of inclusive, empowered leadership and productive decision-making. NC has vast untapped potential and resources in its leaders, organizational governance, community decision making, and collaborations. Extension supported leadership development and partnership building by providing specialized training; hosting in-person, virtual, and hybrid educational programs and presentations; and proactively engaging with a broad range of stakeholders, including community leaders, educators, growers, and consumers. NC State Extension worked with community groups and coalitions to increase collaborative practices and effectiveness, amplifying the capacity of NC's leaders, organizations, and communities to ensure sustainable and equitable prosperity for all North Carolinians.

Community infrastructure – Extension Program

STRENGTHENING COMMUNITY INFRASTRUCTURE AND RESILIENCE TO BUILD FUTURE ECONOMIC, HEALTH, AND SOCIAL WELL-BEING: Evidence of rural stress, broadband connectivity rates and utilization, and the number of communities needing upgraded infrastructure and services affect the state's ability to attract new businesses and residents. The COVID-19 pandemic tested community and government infrastructure at every level, creating unprecedented challenges associated with public health, food security, working conditions, and much more. NC State Extension utilized existing partnerships to distribute masks, hand sanitizer, and food to families in need during the pandemic. Extension was also able to leverage its 101 local Extension Centers across the state to ensure the health and well-being of farmworkers and prevent significant disruption in agriculture production by leading vaccine distribution efforts. COVID-19 also reinforced the critical need to expand broadband access to rural portions of the state. Extension is part of efforts paving the way to ensure that the lack of broadband access doesn't stand in the way of opportunities for our rural communities to thrive.

Local food systems – Extension Program

RESILIENT LOCAL FOOD SYSTEMS THAT PROMOTE FOOD THAT IS GROWN, CAUGHT, AND RAISED WITHIN NORTH CAROLINA: Resilient localized food systems ensure a continual supply of safe, accessible food for all community members while supporting the economic vitality of farmers of all scales. NC State Extension increased access to locally produced food through food assistance collection and distribution programs such as food collection at farmers markets and venison donation programs. With Extension's help, local agribusinesses and farmers markets continued to increase direct consumer spending at farms and markets narrowing the disconnect between consumers and the agriculture community. Extension also fueled the continuous growth of robust local food systems by providing training, education, and guidance to new and beginning farmers. NC State Extension created opportunities to build resilient local food systems that promote food that is grown, caught, and raised within North Carolina.

Improving Plant and Animal Agricultural Systems**Development of advanced phenotyping and molecular tools to improve quality traits in fruit and vegetables - Massimo Iorizzo**

IMPROVED BLUEBERRY CROP QUALITY THROUGH ANALYTICAL TOOL DEVELOPMENT: In blueberry breeding programs selection for fruit quality characteristics using traditional phenotyping methods is expensive, inaccurate and ineffective. To address this issue, NC State researchers developed a high-throughput phenotyping system to evaluate fruit texture and appearance in blueberries. This system measures 28 fruit characteristics and employs an automated system to collect data at harvest and after storage. This data is crucial to evaluating the genetic mechanisms that control texture and shelf-life in blueberries. This new system has been transferred to other blueberry breeding and research programs to advance selection of new blueberry cultivars with improved characteristics. Consumers will benefit from access to a more stable supply of affordable and nutritious fruits with quality characteristics that meet their preferences. This likely increase in per capita consumption and improved human health and well-being is just one way NC State research is feeding our future.

Small grain breeding investigations - Joseph Murphy

VALUE-ADDED SMALL GRAIN BREEDING LINES: The average lifespan of a small grains cultivar in the southern US is 5 seasons. NC State researchers used proven methods to develop superior varieties of wheat, oats, triticale, and rye combined with cutting-edge genetic approaches that support more efficient development of new varieties with characteristics such as disease and insect resistances. In 2020-21, researchers collaborated with public and private partners to develop three wheat lines and two oat lines that are undergoing the cultivar release process. The wheats contain resistance to scab, powdery mildew, leaf rusts, Barley Yellow Dwarf Virus and Hessian fly, combined with superior

yield, test weight and quality. In addition, NC State researchers have presented, for the first time, solid genetic evidence of a Hessian fly field tolerance gene, which will significantly improve breeders' efforts to integrate long-term, sustainable insect resistance into US breeding lines. A sustained production of superior wheat and oat varieties improves farm income, food and feed availability. The reduced use of pesticides on genetically resistant varieties is beneficial to the environment, reduces input costs and should reduce food and feed prices. These are the kinds of results made possible through funding by USDA-NIFA, USDA-ARS, North Carolina Small Grain Growers, Inc., and North Carolina Foundation Seed Producers, Inc.

Tomato improvement for disease resistance, fruit quality and heat stress tolerance - Dilip Panthee

HIGH-PERFORMING TOMATO HYBRIDS: Tomatoes are the second most consumed vegetable crop after potatoes in the US. The development of high-yielding varieties to combat drought, climate change, pests and diseases, and supply chain issues is a way to meet consumer demand and reduce dependency on tomato imports. NC State researchers have developed and identified 3 high-performing tomato hybrids that can potentially be released based on multi-year data and overall performance. Researchers also identified at least 5 breeding lines that can be used as parent plants and eventually released, as well as lines with resistance to key pathogens. Stakeholders were given the opportunity to see the tomato hybrids during a field day, and some growers and tomato industry stakeholders were provided with trial seeds. This research is contributing to the development of additional hybrids that increase yields, increase profitability for growers, reduce prices for consumers, and reduce dependence on imports. Tomato hybrids that are disease resistant not only reduce production costs but also reduce pesticide use, generating positive long-term impact on soil and water quality and human health. Through this and similar breeding efforts, NC State is feeding our future, growing our economy, and empowering growers and plant scientists to overcome grand challenges.

Characterization of tomato infecting viruses and utilizing barley yellow dwarf virus as an expression vector - Timmy Sit

IMPROVED SCREENING TECHNIQUE FOR KEY TOMATO PATHOGEN: Tobamoviruses infect tomato plants and are typically transmitted via infected seeds. The symptoms of this viral infection often don't manifest until later in the growing season, resulting in yield losses and further spread. To address this challenge and mitigate a viral outbreak among tomato plants NC State researchers have developed a simple screening technique to help tomato breeders ensure their seeds are virus free. This test has been shared with tomato breeders and successfully used for seed lot testing, allowing them to take measures to chemically neutralize or discard infected seeds. By ensuring clean tomato breeding stocks, the general public can have more confidence in the health and cleanliness of NC State's newly released tomato varieties. This project's results exemplify the progress being made through the North Carolina Plant Sciences Initiative, a major interdisciplinary effort designed to address the biggest challenges facing agriculture today.

Refining the recommendations of fertilizers based on soil analysis and plant tissue analysis in North Carolina - Luciano Gatiboni

ENHANCED EFFICIENCY OF FERTILIZER RECOMMENDATIONS: Fertilizer recommendations must be constantly updated due to crop yield increases, crop variety selection, soil management, and fertilizer sources. NC State researchers use long-term soil fertility trials and on-farm trials to refine recommendations. Data gathered at NC State provided support for a decision to reduce the rate of phosphorus (P) recommended for corn, soybean, and wheat crops in NC, saving an estimated 5.5 million pounds of P fertilizer annually. This data was disseminated in Extension meetings with farmers, training of Extension agents, technical meetings, and technical congresses. As NC State researchers discover game-changing insights, NC State Extension delivers research-based knowledge to all North Carolinians, helping to transform science into everyday solutions that make agriculture production more profitable and reduce the negative impact of agriculture on environmental quality.

Interactions and management of plant-parasitic nematodes in host plants - Eric Davis

IDENTIFICATION OF NEMATODE-RESISTANT SWEETPOTATO LINES: Plant-parasitic nematodes cause an estimated \$100 billion in global crop losses annually, necessitating the development of resistant crop varieties. NC State collaborated with other universities to develop new approaches for identifying resistant plants. NC State researchers identified 19 lines of sweetpotato that are resistant to the guava root-knot nematode. All but 2 of the lines had very strong resistance. The ability to identify molecular markers and the resistance genes that are associated with this resistance provides a tool to accelerate the development of new cultivars with guava root-knot nematode resistance that can have dramatic economic benefits to growers and consumers alike. Since sweetpotatoes in NC are a \$400 million annual farm gate commodity and significant export crop, as well as a significant crop grown in multiple southern U.S. states and abroad, development of a commercially viable cultivar that is resistant to guava root-knot nematode would be a game changer. This project exemplifies the progress being made through the North Carolina Plant Sciences Initiative, a strategic university effort aimed at solving grand agricultural challenges.

Phylogenetics of emerging plant pathogens - David Rasmussen

SOFTWARE AND GENETIC MODELS TO ANALYZE PLANT AND HUMAN DISEASE: The continued emergence and spread of agricultural diseases presents a major threat to plant and animal health. To address this challenge, NC State researchers are developing new statistical and computational methods to analyze these diseases. In 2021, we developed improved models for tracking the spread of plant diseases through complex agricultural landscapes, created better methods for tracking the exchange of genetic material between disease-causing organisms, and developed better approaches for analyzing the effects of mutations and other genetic changes on disease transmission in plants. We recently released a software package (Espalier) designed to analyze the exchange of genetic materials in plants, including the exchange of genes that affect antibiotic resistance and disease severity, and we provided extensive tutorials to ensure this tool is accessible to other researchers. NC State models and methods have already been used to gain insight into human diseases as well, including HIV, influenza, and dengue fever. This project exemplifies the kind of results being made possible through the North Carolina Plant Sciences Initiative, a strategic university effort aimed at solving grand agricultural challenges.

Management of plant-parasitic nematodes - Charles Opperman

NOVEL PLANT-PARASITIC NEMATODE MANAGEMENT TOOLS: Plant-parasitic nematodes cause major crop losses. NC State researchers have completed over 60 field trials of a technology that involves wrapping planting material with banana fiber paper containing synthetic or natural pesticides. These trials were conducted over a 5-year period in Benin, followed by an additional 50 field trials in Ghana and Togo with an optimized prototype, positioning these countries for commercialization of the technology. Researchers also completed 4 years of field and glasshouse trials on potato crops in Kenya and Uganda. This proof-of-concept paves the way for future African manufacturing of this technology and has the potential to increase yields, food production, and incomes. NC State researchers also developed a technology that delivers microdoses of nematicides to control nematodes, which can greatly reduce application volume, causing less environmental impact and residue, fewer non-target effects, and higher quality produce. Adoption of this technology will also have substantial positive economic impacts for communities. This is just one example of how NC State is growing the future of agriculture in NC and beyond.

Improving quality and reducing losses in specialty fruit crops through storage technologies - Penelope Perkins-Veazie

DATA-DRIVEN STORAGE STRATEGIES TO IMPROVE SHELF LIFE OF SPECIALTY FRUIT: Most specialty fruit crops have a storage life of a few days to a few months. As part of a multistate research project, NC State researchers are developing technologies that will extend shelf life and maintain or improve quality of muscadine grapes and blueberries. NC State researchers recently determined that seeded and seedless muscadines have a storage life of 3 to 6 weeks depending on their genetic characteristics when stored at 3 degrees Celsius and 90% relative humidity. In addition, 60 blueberry

cultivars were held at 3 degrees Celsius for 6 weeks and were found to differ most in maximum firmness and elasticity. These results help growers plan their distribution and marketing to extend shelf life and reduce food waste. Scientists benefit from this insight as they tailor strategies to breed plants for optimal firmness and elasticity. The broader public ultimately benefits by having a broader selection of fruits, having them available for longer periods of time, and by opening up demand that drives more production of these fruits. This project exemplifies the kind of results that NC State research is delivering to feed our future and grow our economy.

Translational approaches to improve management strategies for cucurbit and sweetpotato diseases in North Carolina - Lina Quesada

IMPROVED MANAGEMENT OF CUCURBIT AND SWEETPOTATO DISEASE: NC State has developed a biosurveillance system for precision management of the cucurbit downy mildew pathogen, and host annual disease monitoring plots. This has inspired growers and packers to provide \$400K to date for downy mildew research and to establish a laboratory endowment. Researchers also determined that sweetpotato black rot can be transmitted through cuttings even when they are taken using best practices, resulting in a shift in fungicide applications that reduces disease. Researchers also established collaborations with chemical companies and IR4 to secure registrations for 5 new fungicides for sweetpotato. NC State research in pickling cucumber disease prevention saves growers an estimated \$2.5 to \$6 million annually by providing best practices that reduce fungicide spray volume. These are the kinds of results being made possible through the North Carolina Plant Sciences Initiative, a strategic university effort aimed at solving grand agricultural challenges.

Influence of environmental and cultural factors on weed management in agronomic cropping systems - Wes Everman

IMPROVED INTEGRATED WEED MANAGEMENT APPROACHES: The number of weed species with resistance to multiple herbicides is increasing at an alarming rate. NC State research on integrated weed management systems has provided growers with valuable tools and knowledge, reducing the impact of pesticide applications on non-target areas, reducing weed management costs, and leading to the introduction and adoption of improved management techniques, such as more widespread use of cover crops, early burndown applications, and residual herbicides to keep fields clean leading into the production season. In addition, NC State research on weed control has led to improved understanding of crop-weed dynamics in diverse environments, in turn leading to more effective recommendations for growers. Through NC State's integrated research and Extension weed management program, dozens of presentations have been delivered to thousands of growers, practitioners, and researchers to advance understanding of integrated weed management and improve yields. This project's results exemplify the progress being made through the North Carolina Plant Sciences Initiative, a major interdisciplinary effort designed to address the biggest challenges facing agriculture today.

Weed management in nursery crops and landscapes - Joe Neal

DEVELOPMENT OF AN AUTOMATED/MECHANIZED SYSTEM FOR DIRECTED HERBICIDE APPLICATIONS IN CONTAINER NURSERY CROPS: Weed control is an essential but costly component of any nursery crop production or landscape maintenance system. Despite the availability of numerous herbicides, there are few effective weed control options for some crops and weeds of increasing importance. To address this issue, NC State researchers have developed a prototype automated spray system for directed herbicide applications in container nursery crops. Ongoing testing is underway to evaluate the effectiveness of this sprayer, and results will be reported to nursery crop producers via a webinar in 2022 and presentations at a national American horticulture conference. In addition, researchers are conducting weed control experiments in the field to evaluate methods for combating common nursery and landscape weed species, including species for which limited research data are available. Researchers are also evaluating the safety of newly registered and experimental herbicides on common nursery crops, with a focus on evaluating the safety of herbicides and herbicide/plant combinations for which limited data are available. For example, researchers have provided data to facilitate registration of herbicides to protect Southern Appalachian Christmas tree

production from herbicide-tolerant weeds. In this way, NC State is growing the future and preserving the profitability of NC's agricultural economy.

Economic evaluation of crop insurance, risk, and technology issues in agriculture – Roderick Rejesus

PUBLISHED KEY AGRICULTURAL RISK MANAGEMENT INSIGHTS: To further understand the economic and risk impacts of crop insurance and agricultural technology issues, NC State researchers have conducted research and published 6 articles in the following peer-reviewed journals: the American Journal of Agricultural Economics, the Journal of Soil and Water Conservation, Agricultural and Resource Economics Review, Ecological Economics, and Pest Management Science. These articles provide key information to diverse agricultural stakeholders, including insights into production risk prediction, market and policy shifts, the influence of higher temperatures on plant yields, and the impacts of new and emerging agricultural technologies in the US and in developing nations. Information derived from these research articles provide important implications to policy makers and stakeholders. By providing these insights, our world-leading faculty remain at the forefront of the interdisciplinary innovation that is critical to creating economic, societal, and intellectual prosperity.

Agronomic crop production – Extension Program

RESEARCH-BASED INFORMATION AND NEW TECHNOLOGY TO EMPOWER AGRONOMIC CROP GROWERS TO MAKE BETTER-INFORMED DECISIONS: According to the United Nations-FAO, the world's population will grow from 7.9 billion today to nearly 9.7 billion by 2050. To meet demand, agriculture in 2050 will need to produce almost 50 percent more food, feed and biofuel than it did in 2012. New and hybrid varieties and best management practices are needed to increase crop production efficiency through increased yields, improved quality, and decreased input costs. To support sustainable growth in row crop production, NC State Extension developed innovative products, technology, and research-based agronomic crop best management practices. These innovations and practices were transferred by Extension Specialists and Agents to growers through meetings, research and demonstration plots, field days, expos, workshops, on-farm consultations, and educational media. As a result of the knowledge gained from variety trials, peanut maturity clinics, demonstrations and other Extension programs, row crop growers were able to increase yields and decrease production costs across commodities. NC State Extension is enhancing agriculture in North Carolina that supports thriving communities and provides all North Carolinians access to safe, nutritious food.

Horticulture plant systems – Extension Program

RECOMMENDED BEST MANAGEMENT PRACTICES INCREASED PROFITABILITY AND EFFICIENCY OF HORTICULTURE PRODUCTION: The world's population will surpass 9 billion by 2050. To meet consumer demand, almost 50 percent more food, feed and biofuel will need to be produced. Coupled with this, there is pressure placed on horticulture producers because of climate change, soil erosion, pests, and diseases. To support sustainable horticultural production, NC State Extension has developed innovative products, technology and research-based horticulture best management practices through applied research, diagnostic testing, and variety performance evaluations. To support commercial growers, nursery professionals, resident gardeners, and landscape professionals, Extension promoted the adoption of best management practices through workshops and certification programs, clinics, webinars, technical assistance, community and demonstration gardens, and public outreach efforts. Extension led efforts to curb plant diseases and pests through improved crop management, site selection, variety selection, and pesticide management. As a result of the solution-driven research, technology, education, and technical assistance provided to commercial horticulture producers; they are making better-informed decisions and are increasing the profitability of their operations. By attending NC State Extension's programs, 45,496 participants are using Extension-recommended best management practices in landscapes, turf, and gardens, including pests (insect, weed, disease, wildlife) and soil management. NC State Extension is enhancing agriculture in North Carolina that supports thriving communities and provides all North Carolinians access to safe, nutritious food.

Nutritional strategies to enhance intestinal health and growth of nursery pigs fed AGP-free diets - Sung Woo Kim

DIETARY STRATEGIES FOR ENHANCING NURSERY PIG HEALTH: Pig production is impacted by compromised intestinal health upon weaning, especially in the current era of antibiotic-free production. Innovative nutritional strategies are needed to enhance pig intestinal health. NC State researchers conducted 4 projects to test the effects of dietary interventions on the intestinal health and growth of nursery pigs without the use of antimicrobial growth promoters. The outcomes of this research have been presented at 12 international seminars, symposiums, and forums, and 10 papers outlining the research have been published in tier 1 peer-reviewed scientific journals. These papers have already been cited over 16,017 times, demonstrating that our world-leading faculty are at the forefront of innovation and discovery in animal husbandry.

Microbial fermentation: A dynamic ecology shaping nutritional energetics - Vivek Fellner

SUSTAINABLE APPROACHES TO MANAGING BIODIESEL BYPRODUCT: The use of biodiesel as an alternative energy source has increased the need to sustainably dispose of glycerol, a major byproduct of biodiesel. With the greater introduction of newer byproduct feeds, like glycerol, that are a high energy source, there is a need to better understand the functional role of gut microbes and nutrient exchanges within the gut that will allow us to formulate strategies to enhance nutrient use, minimize nutrient loss, and improve energetic efficiency. To support this effort, NC State researchers have identified natural, biocompatible, non-toxic substances that can be used to capture glycerol, and they have partnered with NC State engineers and the National Engineering College of Egypt to develop and validate methods for this capture. A peer-reviewed journal article discussing the results of this effort has been published, and the project has provided many opportunities for professional development, including technical training of a senior visiting scientist from Egypt and mentorship and training of students and researchers, fostering discussion at the national and international levels, just one example of how our research addresses grand challenges in sustainability.

Identifying factors that reduce the reproductive quality of honey bee queens (*Apis mellifera* L.) - David Tarpy

NEW INSIGHTS INTO HONEY BEE QUEEN HEALTH: Honey bees play a crucial role in pollinating diverse crops. NC State researchers are conducting research to determine the environmental and management factors that influence the longevity and fertility of honey bee queens, since queen problems are one of the major triggers of honey bee colony losses. In 2021, these insights were delivered to beekeeper groups and other stakeholders via 19 presentations and workshops (>2,500 individual contacts) and 15 Extension publications. Moreover, the NC State Queen & Disease Clinic is a unique Extension initiative that enables queen producers and beekeepers to test the health and quality of their queens and colonies in near-real time so that they can optimize their management practices to improve honey bee health and survival. These are just some of many ways that NC State's world-leading faculty are at the forefront of apicultural innovation and discovery.

National animal genome research program - Benjamin Reading

SEAFOOD SPECIES GENOME RESOURCES, TOOLS, AND INFORMATION: The National Animal Genome Research Program provides resources, tools, and information for all agriculturally relevant animal species in the US. NC State supports this program by coordinating efforts on all seafood species. As part of this effort, NC State researchers have developed genetic selection models that improve the ability to predict animal filet yield by 50% and the ability to predict animal body weight by 28%, suggesting that using these models can substantially enhance genetic improvement of aquaculture animals. NC State research has also uncovered insights into disease resistance and environmental adaptation in commercially important fish species. In addition, genetically improved striped bass and white bass broodstock were transferred to industry, and captive bred striped bass seed with 25% better growth were delivered to commercial aquaculture producers. By delivering these insights, NC State is enhancing the value and resilience of domestic aquaculture to grow the economy of NC and the US as a whole.

Pasture pest management: Advancing the IPM tool box - David Watson

ADVANCING TOOLS FOR THE MANAGEMENT OF PASTURE PESTS: The NC cattle industry is plagued by pasture pests, some of which are invasive and demand heavy insecticide control measures, leading to the need for further precautions to protect pollinators and water sources. NC State researchers converted an electric vacuum fly-trap into a propane fueled model to enhance ease of use in dairy cow pasture settings or in any setting in which electricity is not available. The modified trap effectively reduced the number of flies on cattle to below threshold levels (200 flies per animal) within a month without the use of insecticides. Training and presentations were provided to cattle producers on novel fly management practices and new innovative pest management tools available to them. NC State's integrated research and extension programs include ongoing efforts to grow the future of agriculture production with innovative, efficient, cost-effective, and environmentally friendly solutions.

Gut health and prevention of antibiotic persistent foodborne pathogens in poultry - alternatives to antibiotics - Hosni Hassan

ALTERNATIVES TO THE USE OF ANTIBIOTICS IN POULTRY PRODUCTION: Salmonella infection following consumption of contaminated poultry meat and egg products is a major public health concern, which is exacerbated by increasing antibiotic resistance. NC State researchers are addressing this challenge by developing new ways to naturally enhance poultry gut bacteria to defend against antibiotic resistant germs. Researchers have discovered that treating day-old chicks with a specific prebiotic or with an NC State-developed Salmonella vaccine significantly reduced Salmonella growth, and the use of certain essential oils also inhibited the growth of antibiotic resistant Salmonella and E. coli, and it prevented the transfer of antibiotic resistance among different strains of bacteria, all while having no impact on beneficial gut bacteria. Researchers also identified and tested natural compounds produced by immune system cells and found them to be effective in destroying germs regardless of antibiotic resistance. As a result of this work, the public can be assured that their food supply is free of pathogenic bacteria and specifically free of antibiotic resistant bacteria that can transfer the resistance markers to other organisms. Thus, they can rest assured that if they get sick, their treating doctor can find the appropriate antibiotics needed to improve their health. This is just one example of how our world-leading faculty are at the forefront of innovation and discovery in animal health.

Animal production systems – Extension Program

SOLUTION-DRIVEN RESEARCH, TECHNOLOGY AND TECHNICAL ASSISTANCE TO INCREASE PROFITABILITY AND REDUCE ENVIRONMENTAL IMPACT OF THE FOOD ANIMAL INDUSTRY: The world's population is projected to surpass 9.7 billion by 2050 and global meat production will need to increase to 455 million tons (from approximately 350 million tons today) to meet consumption demands. This is alongside a decline in farm and rangelands due to population growth and residential development, and farming's contribution to greenhouse gas emissions, fossil fuels, and other pollutants. NC State Extension is developing climate-smart agricultural practices and innovative ways to increase food animal production on less land. To support increased profitability of animal agriculture producers, NC State Extension transferred information about innovative products, novel technologies, and animal science best management practices to producers through meetings, workshops, certification programs, on farm consultations, websites, webinars, factsheets, and newsletters. Extension also helped producers develop disaster, disease, and waste management plans. As a result of the solution-driven research, technology, education, and technical assistance provided to animal agriculture producers; they are making better-informed decisions and increasing profitability while decreasing the environmental impact of their operations. NC State Extension is enhancing agriculture in North Carolina that supports thriving communities and provides all North Carolinians access to safe, nutritious food.

Protecting Environmental and Natural Resources

Evaluation of ecosystem services and performance criteria in restored wetlands - Michael Vepraskas

IMPROVED EVALUATION OF WETLAND RESTORATION: Wetlands that have been drained and used for agriculture can be restored to support environmental health, but the process is expensive. To address this challenge, NC State researchers have developed statistical models to assess wetland restoration. Thanks to this effort, wetland regulators have new tools to evaluate and enhance wetland restoration in order to improve water quality, mitigate flooding, and provide wildlife habitats that play valuable roles in ecosystem preservation. Through this project, NC State is transforming science into practical solutions that enhance environmental resilience and serve all North Carolinians.

Onsite wastewater treatment systems: Assessing the impact of soil variability and climate change - Matthew Ricker

UNDERSTANDING SEPTIC SYSTEM VULNERABILITY TO SEA LEVEL RISE: Millions of people live in coastal regions of the eastern US. Coastal climate change is predicted to cause increased flooding, salinization of soils, and rising ground water tables. These factors will likely negatively affect the ability of existing septic systems to treat waste and protect water quality. NC State researchers analyzed geospatial data from 7 coastal counties to evaluate septic system vulnerabilities. Preliminary research has located 30,361 coastal systems that are within 500 m of the coastline and likely at risk because of sea level rise over the next century. This data can be used by land managers to predict problematic landscapes for future installation of on-site systems and target areas where failure of previously installed systems is likely to occur. In coastal communities this data is being used in extension activities to inform the public about coastal septic systems, water quality, and human health. Digitized site-specific paper soil maps have been compiled and will be available for the entire Outer Banks region of NC in 2022 to support the economic, social, and environmental welfare of North Carolinians. This is just one example of how NC State research is preserving natural resources and proactively addressing future impacts from climate change.

Measuring soil physical property dynamics - Josh Heitman

IMPROVED SOIL ANALYSIS TO ENHANCE SOIL MANAGEMENT TECHNIQUES: Soil processes for agricultural, engineered, and natural systems are greatly affected by dynamic soil arrangement (i.e., the structure and density of soil). NC State researchers have developed a framework for measuring and modeling these dynamic soil parameters that has the potential to be integrated into crop and soil management models. NC State researchers also analyzed the effectiveness of compost in reducing runoff, improving runoff quality, and increasing the establishment of vegetation in unstable subsoil conditions, and have demonstrated that compost incorporation via tillage was an effective management strategy. This research was shared through 14 refereed research publications and through presentations at scientific meetings, and it lays groundwork for enhanced monitoring and management of soil resources, particularly in degraded soil environments. This is just one example of how NC State is translating research into practical solutions that address grand challenges in agriculture.

Quantification of land use effects on soil ecosystem services in depositional landscapes - Matthew Ricker

ENHANCED KNOWLEDGE OF FLOODPLAIN SOILS TO IMPROVE LAND USE AND CONSERVATION PLANNING: NC State researchers are using a soil survey approach to quantify nutrient storage and improve floodplain maps to identify priority areas for management and conservation, reducing the uncertainty surrounding the nutrient (carbon and phosphorus) concentrations in the vegetated riparian zones next to natural water sources. Researchers identified and sampled 110 forested, agricultural, and urban sites across NC, an effort that represents the most comprehensive evaluation of floodplain soils in the state. The findings suggest that urbanization may limit the ecosystem resources provided by the forested floodplains of the Southeastern US. NC State researchers have also reduced the uncertainty of wetland locations in broadly mapped floodplains from 45% to 20%, and these methods

can be employed statewide to enhance land use and conservation planning. Numerous NC land managers have inquired about this research for applications in geoscience, forestry, and infrastructure construction planning. This effort exemplifies how our world-leading faculty and exceptional field faculty are providing high-tech, high-touch expertise to safeguard the environment and serve the unique needs of diverse clients.

Pesticide and trace element fate and behavior in the environment – Travis Gannon

INFORMED SUSTAINABLE, SAFE PESTICIDE MANAGEMENT PRACTICES: Understanding the impact of pesticides on the environment is critical in order to avoid adversely affecting human or environmental health while meeting agronomic goals. NC State researchers are working to characterize the fate and behavior of experimental and recently registered pesticides, as well as organic arsenic-based herbicides. Collaborative research in this project also includes leading a portion of a USDA-SCRI grant investigating the mechanisms of annual bluegrass herbicide resistance in various crop and specialty systems. By characterizing the fate and behavior of pesticides and trace pesticide components among various systems and seasons, evaluating the potential of various pesticides to cause adverse effects on nontarget species, and determining if certain herbicides may cause adverse effects in subsequent cropping systems, NC State researchers are guiding the development of new best management practices that significantly benefit growers. These practices include the use of phytoremediation, a plant-based approach to removing or limiting the effects of pollutants in soil, and the use of chemicals to extract trace pollutants from soils. Helping growers more safely and effectively use pesticides is just one example of how NC State is growing the future of NC agriculture and serving all North Carolinians.

Poultry litter management in North Carolina - Stephanie Kulesza

IMPROVED POULTRY LITTER MANAGEMENT APPROACHES: Agronomic crop growers were interested in knowing whether application of poultry litter improves crop yields and quality. NC State researchers found that soybean crops do not benefit from the application of nitrogen in the form of poultry litter or inorganic sources at the beginning of the season. However, the application of poultry litter did not negatively impact soybean crops, indicating that litter can be applied to meet other nutrient requirements (phosphorus and potassium). This information was provided to growers through grower meetings and other Extension events, enabling growers to be more confident in their litter application decisions and tailor those decisions to meet phosphorus and potassium requirements. Through this integrated research and extension project, NC State is translating research-based knowledge into everyday solutions to grow the future of NC agriculture.

Understanding and managing ecological effects of urbanization from organismal to landscape scales - Elsa Youngsteadt

APPROACHES TO SUPPORT WILD BEE DIVERSITY AND CONSERVATION: To address emerging challenges associated with climate warming in urban and non-urban landscapes and protect local pollinators, NC State researchers conducted a groundbreaking comparison of bee sampling methods used to capture data about bee populations and identified an approach that accurately quantifies populations. In addition, NC State held a bee hotel building event and workshop to teach over 100 participants how to create and maintain good habitats for bees. Researchers also fielded inquiries from stakeholders about bee hotel design and maintenance and prepared a peer-reviewed Extension document to support these activities (planned for release in 2022). In addition, 800 stakeholders were reached via 6 Extension and outreach presentations on the topic of wild bee diversity and conservation. In addition, NC State's identification guide for NC bees was accessed 12,842 times in 2021, and research results were delivered in 5 scientific presentations, 3 scientific publications, and 5 public presentations. This demonstrates how NC State's research faculty constantly partners with NC State Extension to deliver research-based knowledge to all North Carolinians, helping them transform science into everyday solutions that grow our future.

A carbon-negative bioeconomy: Leveraging bioprocess synthesis, applied engineering, and techno-economic-life cycle analysis to utilize and sequester carbon dioxide - William Sagues

INSIGHTS TO SUPPORT A CARBON-NEGATIVE BIOECONOMY: To support meeting stringent requirements established by the Intergovernmental Panel on Climate Change (IPCC), the US must transition to a “carbon-negative” bioeconomy in which processes and products result in a net reduction of CO₂ in the atmosphere. NC State researchers have participated in over \$9 million worth of grants aimed at achieving this goal and have already established preliminary data to enable removal of carbon dioxide in several industries, including animal protein, pulp, and paper. Over 10 presentations were delivered to stakeholders at conferences and workshops, and 5 publications were produced. NC State researchers are in the early stages of developing several carbon-negative bioprocesses, and several current and pending projects have close ties to large corporations (e.g., Novozymes, Rayonier, Sunrock), demonstrating their potential for significant, near-term impact. NC State has also partnered with the Oak Ridge National Laboratory to make crucial data available to the public, and these data are already being used by large bioprocessing companies (e.g., Rayonier, Meati) to scale up their biorefining technologies. This is just one example of how NC State’s cutting edge, solution-driven research, technology, and scholarship fuels sustainability and economic development.

Keeping afloat in the data deluge: coupling observational data, analytics, and integrated models to propel data-driven biological resources management - Natalie Nelson

ENHANCED AGRICULTURAL DATA ANALYSIS: To advance biological resource management, NC State researchers are bringing data science into the fore of biological systems research by developing and presenting a series of case studies to demonstrate how practitioners can extract useful information from raw data, including satellite imagery, high-frequency measurements collected in the field, and long-term monitoring records. These case studies include monitoring coastal and ocean data, helping shellfish producers forecast weather to optimize harvest schedules and other operations, using data science to cultivate a resilient agricultural workforce, observing harmful algae, and advancing data-driven sweetpotato production. NC State researchers also provided professional development opportunities to instruct 5 PhDs, 2 master’s degree students, 6 undergraduate students, and a postdoctoral researcher in best practices for environmental and agricultural data analysis and led a USDA NIFA-funded research and Extension experience to train an additional 10 undergraduates in the principles of data science. This is just one example of how NC State’s trusted cutting-edge, solution-driven research is fueling agricultural and environmental sustainability throughout the state and empowering better-informed decisions.

Emerging and legacy contaminants in aquatic ecosystems: examining their transport, fate, and biological effects - W Cope

ILLUMINATED ENVIRONMENTAL IMPACT OF “FOREVER CHEMICALS”: The environment and human health are threatened by “forever chemicals,” human-made chemicals found in products engineered to resist friction and heat that persist in the environment indefinitely. NC State researchers conducted a study measuring contamination levels for 14 key forever chemicals along the entire food chain of the Yadkin-Pee Dee River, a major Atlantic coastal river. These chemicals were found in every step of the food chain despite the fact that the river does not have a known industrial input of these compounds. This study identifies strong links between ecosystem groups that lead to the buildup of these compounds in animals and humans that sit higher on the food chain. These findings will directly inform natural resource management and human health-related policymaking at the state and federal levels, leading to a greater understanding of the consequences of exposure to forever chemicals. Through this and similar efforts to address systemic environmental threats, NC State is strengthening communities and serving all North Carolinians.

Environmental and natural resources – Extension Program

PROGRAMS TO CONSERVE AND PROTECT THE ENVIRONMENT, BOOST SUSTAINABLE ENERGY, AND MITIGATE CLIMATE CHANGE: Climate change, deforestation, air pollution, water pollution, loss of wildlife, and natural resource depletion threaten our ecosystems, increase rates of disease, decrease security (food, water, air), raise sea levels and temperatures, and cause severe weather events. NC State Extension led efforts to sustain the quality and diversity of North Carolina's natural resources by conserving and protecting the environment, boosting sustainable energy, and mitigating climate change. As a result of Extension's efforts, a tool was created that minimizes off-target movement of herbicides. Extension also increased the safe application of pesticides and use of alternate control measures through pesticide safety training and IPM workshops. NC State Extension improved water quality through workshops on the protection of riparian buffers, workshops and implementation of stormwater BMP projects, and streambank repair efforts. Extension educated local communities about composting and recycling, hosted pesticide container and used oil recycling events, and litter clean-up days and successfully reduced their negative impact on the community and environment. NC State Extension provided the means for North Carolina's natural resources and environmental quality to be protected, conserved and enhanced, and ecosystem benefits optimized.

Appendix**Includes Full Text of Results Reports****Research Projects**

Enhancing Food Safety, Nutrition and Health: 22 projects/ 5 with 0 results
Enriching Youth, Family & Community Well-Being: 12 projects/3 with 0 results
Improving Plant and Animal Agricultural Systems: 151 projects/ 36 with 0 results
Protecting Environmental and Natural Resources: 62 projects/ 21 with 0 results

Extension Programs

Enhancing Food Safety, Nutrition and Health: 2 programs
Enriching Youth, Family & Community Well-Being: 6 programs
Improving Plant and Animal Agricultural Systems: 3 programs
Protecting Environmental and Natural Resources: 1 program

Other Projects & Programs

Without a Critical Issue: 4 (2- multistate admin & 2- because of system issues with IACUC approval dates)
Multistate: 38 (duplicated results reports from research projects that have multistate flag)
Integrated: 92 (duplicated results reports from research projects & extension programs that have integrated flag)