

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 portfolio of cutting-edge, solution-driven research transforms science into everyday solutions that is extended to all North Carolinians through N.C. Cooperative Extension to improve lives and grow our state.

From the food that nourishes us and the fiber that clothes us to the ornamentals that brighten our lives and provide ecosystem services – we work on the plants, animals and microbes that sustain us. We live our land-grant mission, supporting individuals, families, communities and businesses in our constant quest to improve lives and provide opportunities for all across our state. We research the fundamentals of biology, agriculture and ecosystems; of family and community dynamics; of physics, data and technology; and of educational and extension theory. We turn that basic knowledge into innovation that delivers new technologies, new crops, new processes, and new ways of addressing challenges on our farms and in our homes, communities and businesses. We bring knowledge to our students and external constituents, and we educate and train the people who make all of this happen.

Throughout 2023, the North Carolina Agricultural Research Service (NCARS) and NC State Extension prioritized efforts aimed at solving the complex challenges facing food and agriculture. Innovative partnerships, entrepreneurial thinking and applied problem-solving are vital to everything we do. Our partnerships engage at all levels — among individuals, departments, colleges, universities; across disciplines; across the research, teaching and extension functions; and with private citizens and businesses, nonprofit organizations and local, state, federal and foreign governments. CALs had a productive year in research, scholarship, innovation and collaboration. CALs reached, for the first time, a level of external grant and contract funding that exceeded \$100 million (\$105,480,015). Vital infrastructure needs were also addressed as CALs completed a \$13.9 million five-year investment in repair and renovation of on-campus and off-campus facilities. Extension efforts continue to be prolific at the 101 Extension Centers, 18 research stations and 4 NC State Field Labs throughout the state. We continue to improve N.C.'s top cash crops and add \$2.1 billion in economic impact to N.C.'s economy. We provided more than 25,000 educational programs statewide, 136,000 educational outreach activities, and produced 343 new or revised publications. The University successfully completed a national search for a new Dean for the College of Agriculture and Life Sciences. Dr. Garey Fox took over the helm of the college on August 1, 2023.

Critical Issue: Improving Plant and Animal Agricultural Systems

NC State researchers have undertaken a wide range of studies to address agricultural challenges and improve crop and livestock production systems. For instance, researchers found that incorporating cotton gin byproduct into cattle feed can significantly reduce feed costs while maintaining excellent weight gain and carcass value in cattle. This research supports the adoption of cotton gin byproduct by feed marketers and producers, promoting environmentally friendly production systems. By evaluating four laying hen varieties, researchers identified differences in egg production, body weight, and egg size in cage-free environments. This data helps egg producers select suitable hen breeds for cage-free production systems, contributing to

animal welfare and meeting consumer demands. NC State research on cage-free systems revealed methods to reduce forage destruction and soil erosion using essential oils and geogrids. Additionally, researchers identified alternative poultry feed ingredients from peanut and sweetpotato byproducts, supporting sustainable and cost-effective egg production. When studying sow nutrition and reproductive efficiency, researchers found that supplementation with essential fatty acids and fiber improved sow reproductive efficiency without impacting body weight. These findings have been implemented by segments of the pork industry to enhance sow health and productivity. Boar reproductive development was examined and findings demonstrated that providing male piglets with extra colostrum enhances reproductive development and immune system strength, reducing disease risk and improving sperm production in boars. NC State participates in the National Animal Genome Research Program, contributing to advancements in animal genomics. Their efforts have significantly expanded the hybrid striped bass industry and supported breeding programs across various animal agriculture industries. NC State researchers are developing innovative methods for raspberry cultivation and identifying cost-effective growing media alternatives for berry crops. Additionally, new and improved berry varieties will soon be available to growers, enhancing crop productivity and profitability. NC State's contributions to cotton genetics research have led to the development of improved cotton germplasm lines with enhanced disease resistance, fiber quality, and yield, supporting the economic viability of cotton production. A more efficient genotyping pipeline for peanut cultivars is being developed, enabling quicker development of disease-resistant varieties and improving peanut production efficiency. The NC State Sweetpotato and Potato Breeding and Genetics Program has made significant strides in developing highly productive and resilient sweetpotato cultivars, contributing to food security and economic stability. Studies on phosphorus availability in soil and crop adaptation are contributing to the development of more efficient phosphorus utilization in corn and sorghum, supporting sustainable agriculture practices. NC State's Small Grains Program has supported small grain growers with actionable insights and international collaborations, leading to increased wheat yields and improved production practices. Research on plant-parasitic nematodes has led to improved understanding and management strategies, including the discovery of effective crop rotation methods to reduce nematode populations. These studies and others collectively contribute to the advancement of sustainable, efficient, and resilient agricultural practices, addressing various challenges faced by crop and livestock producers in North Carolina and beyond.

NC State Extension has made significant progress in bolstering North Carolina's agricultural sectors. Through research-based initiatives, Extension efforts have facilitated increased yields, reduced production costs, and enhanced sustainability across various crops, livestock, and poultry. Extension efforts have been disseminated through diverse channels such as workshops, field days, online platforms, and one-on-one consultations, leading to improved practices and profitability for producers. Additionally, emphasis has been placed on environmental stewardship, community engagement, and empowering stakeholders with practical knowledge and resources for informed decision-making, ultimately fortifying the state's agricultural economy and promoting access to safe, nutritious food.

Critical Issue: Protecting Environmental and Natural Resources

Researchers at NC State addressed various agricultural and environmental challenges through multiple studies. Researchers evaluated corn and soybean hybrids under different water stress conditions using drone technology. Their findings highlighted the economic impact of hybrid selection on grower revenue and emphasized the benefits of managing irrigation and drainage throughout the growing season. Other researchers focused on floodplain soils in the Southeastern US, aiming to improve floodplain maps and assess carbon and phosphorus content. Their research identified priority areas for management and conservation, revealing the potential impact of urban development on floodplain ecosystems. In other studies researchers investigated phosphorus transport from fertilizers to improve fertilizer efficiency and reduce over-application on soils. They introduced an innovative soil track system for evaluating nutrient release and movement, facilitating faster comparison of different fertilizers and potentially leading to the development of more efficient products. Researchers studied the impact of soil treatments on nitrous oxide emissions and crop yields. They found that certain treatments did not increase emissions and discovered inaccuracies in emission measurement methods. Their findings contribute to informed decision-making on sustainable soil management and benefit farmers seeking to enhance their operations. NC State researchers developed a model to simulate the life cycle of blue crabs and assess the effects of environmental stresses on their population dynamics. Their study provided insights into the resilience of NC's blue crab population to climate change and other stressors, aiding in resource management along the coast.

NC State Extension provided education and resources to approximately 25,000 commercial pesticide applicators and 13,000 private pesticide applicators in North Carolina. Efforts were made to ensure compliance with changing regulations to protect the environment and worker safety. Additionally, Extension was involved in initiatives to address pesticide pollution through training programs, recycling assistance, and disposal programs. Extension was also involved in efforts to study and educate the public on perfluorinated compounds (PFAS) in water sources and their impacts on human and animal health, as well as efforts to understand saltwater intrusion due to climate change and its effects on agricultural lands. NC State is committed to integrated research and extension activities aimed at protecting public health, water resources, livestock, and agricultural products, while also providing tailored expertise to address the diverse needs of clients.

Critical Issue: Enhancing Food Safety, Nutrition and Health

NC State researchers have isolated chicken-specific Lactobacilli to enhance poultry gut health and combat antibiotic-resistant Salmonella and Campylobacter. They sequenced the genomes of four Lactobacilli strains, identifying genes crucial for antimicrobial peptide production. Demonstrating that species-specific probiotics result in better host colonization, this research offers poultry producers a means to ensure safer and more profitable products, benefiting both industry and consumers. Research conducted at NC State investigated the disease-prevention potential of phytochemical-rich foods like blueberries, cocoa, tea, and artichokes. By studying their effects on gut bacteria and trimethylamine production, researchers identify dietary strategies to reduce cardiovascular disease risk. This research contributes to understanding how plant foods can mitigate chronic and life-threatening illnesses. NC State collaborated with other

universities to advance food process engineering. They characterized raw and processed foods, developed sustainable processing technologies, and created mechanistic models for food manufacturing optimization. Specific projects included plasma electrode development for produce sanitation, research on plasma-activated water for egg washing, high-pressure processing for plant-based proteins, and validation of sanitation efficacy using enzyme-based surrogates and machine learning, all contributing to safer, higher quality, and more health-promoting foods. NC State's continuous flow microwave processing technology enables the creation of new nutrient-dense foods, including shelf-stable sweetpotato purees. Collaboration with companies and organizations like Yamco, SinnovaTek, and the UN/US World Food Programme highlights the technology's impact on reducing waste and addressing nutritional deficiencies on a global scale. NC State researchers explored electrolyzed water (EW) as a low-cost, environmentally friendly antimicrobial treatment for oysters contaminated with *Vibrio* bacteria. Sequential applications of alkaline and acidic EW effectively reduce non-disease-causing bacteria, offering a scalable and sustainable solution to reduce foodborne illness, benefiting public health and the food industry.

NC State Extension addressed the importance of food safety and nutrition education in North Carolina. Efforts include providing resources and training on safe home food handling, preservation, and preparation practices, resulting in increased knowledge for over 140,000 participants. Additionally, the Safe Plates program offered training to food service employees and managers, enhancing their skills in safe food handling. The Expanded Food & Nutrition Education Program (EFNEP) supported limited-resource families with nutrition classes, cooking skills, and food safety knowledge, leading to improved diet quality and food management skills. The Steps to Health program focused on community-level interventions to promote healthy living, impacting over 117,000 individuals through initiatives to increase access to healthy food options and encourage physical activity.

Critical Issue: Enriching Youth, Family & Community Well-Being

NC State's Farm to Early Care and Education (ECE) local food procurement research aimed to facilitate local food procurement for early care and education programs. Through exploratory case studies, three procurement strategies were developed and piloted across four counties, focusing on aggregating orders, selling to families, and working with caterers. Preliminary findings suggest successful models that increase market viability for farmers while meeting ECE providers' needs. Researchers at NC State explored the experiences of farmers in North Carolina, South Carolina, and Virginia regarding financial distress and mental health crises. Findings reveal coping strategies, community networks, and institutional support systems crucial for navigating stressors and promoting resilience among farmers, with implications for service provisioning and community-based interventions. In other research, interviews with small-scale niche-market meat producers in North Carolina highlighted their adaptations to COVID-19 disruptions, including product diversification and market expansion. Farmer-to-farmer organizations played a vital role in providing resources and social support, contributing to the resilience of these producers amidst uncertainties in the agricultural sector. Research on *Aedes albopictus* (tiger mosquito) population dynamics and insecticide resistance informed mosquito control strategies, benefiting private control companies and public health officials. The study identified integrated pest management as a solution to maintain profitability and effectively control mosquito-borne diseases. Other research on flies and mosquitoes focused genomic research on dipteran species which provided insights

into genetic change, evolutionary history, and species interactions. This collaborative effort produced valuable data for biodiversity assessment, pest control, and understanding the origins and spread of disease vectors.

NC State Extension plays a pivotal role in educating and empowering North Carolinians across various domains, including agriculture, youth development, food security, economic development, community development, infrastructure, and local food systems. Efforts are focused on enhancing knowledge and skills related to agriculture, food production, and food safety among youth through programs like 4-H and school-based initiatives. Extension also addresses civic engagement, cooking skills, environmental education, and STEM learning through diverse programs and clubs, reaching thousands of youth annually. Moreover, Extension collaborates with community organizations to increase access to healthy food, provide economic support to small-scale farmers, and offer digital skills education to older adults and other community members. The emphasis on building resilient local food systems and supporting agricultural economy underscores the importance of Extension in promoting sustainable practices and fostering community well-being in North Carolina.

Highlighted Results

Critical Issue 1: Improving Plant and Animal Agricultural Systems

Enhancing poultry production systems and technologies – Aaron Kiess, Poultry Science

To satisfy consumer demands and potentially enhance animal well-being, the egg industry is shifting to cage-free production. To support producers during this transition, NC State researchers evaluated the performance of four laying hen varieties, revealing that Bovans Brown hens produced the most eggs per hen with the highest yolk color, whereas the Hy-Line Brown had higher body weights and produced more extra-large eggs when compared to the white strain laying hens. Genetic analysis suggests that different breeds may experience different levels of stress in a cage-free environment, and a cage-free environment may not be the best choice for certain hen breeds. This data helps egg producers make more informed selections of laying hen varieties for cage-free production. Some of the project results were shared at the International Poultry Scientific Forum and a Poultry Science Association meeting in 2024. The project is also anticipated to result in at least two peer-reviewed journal articles and two Extension bulletins in 2024.

Enhancing poultry production systems through emerging technologies and husbandry practices – Kenneth Anderson, Poultry Science

The egg industry faces numerous challenges to safe, sustainable, high-quality production, including the shift to cage-free production, the need to reduce costs and enhance sustainability, and the need to efficiently, humanely depopulate flocks carrying Highly Pathogenic Avian Influenza (HPAI). NC State research on cage-free systems reveals that essential oils and geogrids (soil reinforcement materials) can be used to significantly reduce forage destruction and soil erosion in cage-free production operations. As a result, geogrid costs have been added to the Natural Resources and Conservation Service cost-sharing system for cage-free egg and poultry meat producers. In addition, researchers have identified byproducts from peanut and sweetpotato production that can be used to make poultry feeds more sustainable and cost-effective, and they

have completed studies on additional alternative feed ingredients that could improve gut health and layer performance. They have also provided industry and the USDA with tools that can be used to humanely depopulate diseased flocks, including development of a hyperthermic process that was used extensively in 2022-23 by USDA veterinary medical officers.

Improving sow productivity through nutrition – Petrus van Heugten, Animal Science

To keep up with consumer demand, producers in the pork industry have progressed to producing more than 25 pigs per sow annually, which greatly increases the nutritional requirements of sows. To improve sow nutrition and maintain productivity, NC State researchers evaluated the impact of essential fatty acid and fiber supplementation on the health, welfare, and reproductive efficiency of sows. The collected data suggest that supplementation with linoleic and α -linoleic acid, at least for mature sows, can increase embryo survival rates and reduce the number of sows removed from the herd. Research results also suggest that high fiber supplementation during pregnancy and additional fiber given immediately before and after delivery did not influence sow body weight, but it did shorten weaning periods and positively impact piglet survival. Research results and practical application strategies were provided through abstracts, peer-reviewed manuscripts, and popular press articles, and resulting nutritional recommendations have already been implemented by a segment of the pork industry.

Alternative concentrates, forages and forage management strategies for beef cattle production in the Southern US – Matt Poore, Animal Science

Feed accounts for more than 50% of production costs for livestock enterprises. For beef producers in the Southern US, these high costs limit profits. To reduce feed costs, NC State researchers studied the nutrient qualities of cotton gin byproduct, a very inexpensive and underutilized potential feed ingredient. A feeding trial revealed that cotton gin byproduct levels of up to 40% in feed were associated with excellent weight gain in cattle as well as excellent finishing performance and carcass value. This research is ongoing, but the initial results support the increasing adoption of cotton gin byproduct by feed marketers and producers. By encouraging producers to incorporate byproducts into cattle feed, cattle enjoy high-quality balanced diets at significantly reduced cost, while landfill disposal of agricultural byproducts is reduced, contributing to a more secure, environmentally friendly production system.

Neonatal factors affecting adult sperm production in boars – William Flowers, Animal Science

Boars are used for short, limited periods of time in the swine industry to maximize genetic improvement, so it is crucial to maximize their sperm production. Research indicates that nearly 50% of the variation in adult boar sperm production is associated with how they are managed from birth to weaning. NC State researchers conducted studies to determine the critical factors affecting sperm production. They discovered that providing male piglets with extra colostrum (the highly nutrient-dense milk that is released by nursing sows the first day after piglets are born) is a quick, effective, economic way for commercial producers to enhance the reproductive development of boars and strengthen their immune systems, reducing their disease risk as their own immune systems mature. The results of this research were presented at two international conferences in 2023.

National animal genome research program – Benjamin Reading, Applied Ecology

The NSRP-8 National Animal Genome Research Program is a collaboration between multiple institutions, researchers, and stakeholders aimed at advancing knowledge of animal genomes (the complete set of genetic material present in an animal). NC State researchers participate in this program, supporting efforts to enhance the quality of available animal genomic data. In addition, NC State has helped advance tools that can more efficiently generate high-quality, comprehensive genomic data sets. NC State genomics and breeding research has already been used to significantly expand the hybrid striped bass industry, the fourth largest form of finfish aquaculture in the US, with an annual farm gate value of over \$50 million. It is estimated that 90% of hybrid striped bass produced for food in the US are derived from animals raised by NC State's breeding program. These ongoing efforts facilitate breeding programs that support all major land and sea animal agriculture industries in the US.

Breeding and novel production systems of small fruit crops – Gina Fernandez, Horticultural Science

With a total cash receipt value of over \$87 million annually, berry crops play an important role in NC's economy. NC State researchers use both traditional breeding and cultural practices to help berry growers produce superior fruit crops. Researchers are currently developing a system to grow raspberries in tunnels during the spring, in a region where raspberries are typically not able to tolerate the heat and humidity. In light of recent shortages of traditional growing media (peat and coconut coir), NC State researchers have also identified a pine bark growing medium similar to traditional media that can be sourced locally at 1/8th the cost of coconut coir. Yield trials in 2022 and 2023 demonstrated that use of the alternative medium did not impact the yield of the raspberry cultivar Kwanzaa, so pine bark can be used immediately by growers to reduce their costs. In addition, thanks to NC State berry breeding research, new and improved varieties of strawberry, blackberry, and raspberry will be available to the public in the next three to five years.

Development of AI-enabled robotic solutions for high-throughput plant phenotyping and automated crop production – Lirong Xiang, Biological & Agricultural Engineering

Manually measuring plant phenotypic traits (observable characteristics resulting from the interaction of a plant's genetics with its environment) is time consuming, labor intensive, and prone to inaccuracy. These challenges make it difficult for plant breeding programs to rapidly select and breed plants with improved yield and resilience. NC State researchers created advanced AI algorithms designed to analyze and interpret complex plant data, developed robotic systems to collect in-field data, and designed intuitive user interfaces to simplify data analysis for researchers and growers. These advances allow breeders to conduct large-scale data analysis with unprecedented efficiency and precision, streamlining breeding programs and supporting rapid development of improved crops to meet global food demands. The AI algorithms are also open source, meaning that they can be modified to benefit not only agriculture but also a broad range of other fields, such as environmental monitoring, conservation, urban planning, and healthcare.

Insect-specific target systems for the development of novel tools for insect control – Coby Schal, Entomology and Plant Pathology

Household and agricultural pests pose a threat to public health, quality of life, and food security. NC State researchers have analyzed the behavior and biology of bed bugs, cockroaches, and the fall armyworm (FAW) to support more effective control measures for these pests. Their findings

highlight the importance of histamine as a potential target for reducing the negative health impacts of household bed bug infestations. They also identified an existing class of veterinary drugs and a new active ingredient with great potential to control bed bug infestations in poultry farms. Studies on cockroach behavior and biology yielded insights into the design of more effective baits, and researchers discovered and patented a new FAW sex pheromone component that, when added to commercial lures, increased male catches by 53-135% in sorghum and cotton fields.

Improving the cotton productivity and sustainability through translational genomics and breeding in cotton – Vasu Kuraparthi, Crop & Soil Sciences

As a leading natural fiber crop and source of plant oil and protein, cotton is an important crop supporting rural communities and industry. Cultivated cotton is vulnerable to many forms of stress, and cotton genetics research lags behind that of other major crops. To address these challenges, NC State researchers have contributed heavily to improved understanding of cotton genetics, including developing and releasing cotton germplasm lines with improved disease resistance, fiber quality, yield, and leaf shape and developing the largest set of publicly created genetic mapping resources for cotton. These efforts have dramatically expanded the cotton genetics knowledge base and identified genetic traits, tools, and new methods that will allow breeders to develop superior, climate-resilient cotton cultivars. This research plays a key role in ensuring the economic viability of cotton production and maintaining the competitiveness of US cotton in international markets.

Integrated disease management and farming systems research in vegetables and strawberries – Frank Louws, Horticultural Science

To increase the long-term food security of the US, we must develop systems-based farming approaches to improve soil health and increase crop yield and quality. Strawberries and tomatoes are valuable targets for production system improvements, returning over \$21.4 million and \$37.4 million in annual farm gate income, respectively. NC State is leading interdisciplinary collaborations to address complex production problems in these crops. A key insight yielded so far is that waste products from other agricultural operations have the potential to be used in place of fumigation to control common soil-borne, disease-causing fungal pests in strawberry and tomato. Although research is ongoing, the use of agricultural waste products to “smother” certain pests appears to be highly effective. This integrated pest management research has been published in papers, abstracts, and Extension products in English and Spanish, ensuring that growers and other stakeholders have access to efficient, sustainable solutions for crop production.

Leveraging computational modeling for data-driven decisions in value-added supply chains for food and energy – Daniela Jones, Biological & Agricultural Engineering

Computational data modeling can guide decisions that enhance the efficiency, sustainability, and resilience of food and energy systems, improving rural economies and reducing environmental impacts. But data science is underutilized in agriculture. To address this issue, NC State researchers have made numerous contributions, including creation of an optimization model to support the development of a sustainable bioeconomy, reduce reliance on fossil fuels, and efficiently produce food, feed, fiber, and fuel. This model can run in less than 25 minutes while achieving a margin of error of as little as 3%, and it could facilitate the analysis and development of a nationwide supply chain of energy crops for the sustainable production of aviation fuel.

Researchers have also contributed models, analyses, and data dashboards to help stakeholders make data-driven decisions to optimize crop yields.

Sweetpotato breeding and genetic enhancement – G. Craig Yencho, Horticultural Science

NC is the leading supplier of sweetpotatoes in the nation, and the development of more resilient, highly productive varieties is among the highest priorities for NC sweetpotato growers. The NC State Sweetpotato and Potato Breeding and Genetics Program has made significant progress in supporting growers, including release and commercialization of highly productive cultivars well adapted to the Southeastern US; collaborative development of genetic mapping, gene editing, and new analytical tools for sweetpotato improvement; multiple partnerships with the International Potato Center funded by the Gates Foundation to support food security and food resilience in Sub-Saharan Africa; and development of a highly focused transdisciplinary project to control the guava root-knot nematode, an emerging pest that threatens the entire SE US sweetpotato industry. Through these and many other efforts, NC State researchers are safeguarding the productivity of a crucial, nutrient-dense crop that plays a key role in food security at the national and international levels. In addition, Covington, released by the program in 2005, has generated over \$4 billion in farm-gate revenue for NC and US farmers, making it one of the most impactful varieties released by NC State.

The genetic architecture of maize phospholipid metabolism adaptation to low phosphorus environments – Ruben Rellan-Alvarez, Biochemistry

Phosphorus is a critical nutrient for plant growth and development, but there are significant gaps in knowledge regarding how genetics affects their ability to take up and use phosphorus. To help growers adapt to rising fertilizer prices and prepare for potential phosphorus fertilizer shortages, NC State researchers studied how corn and sorghum crops adapt to varying levels of phosphorus availability in soil. These studies are contributing to the identification of specific genetic components that could be instrumental in breeding new varieties with an enhanced ability to efficiently use phosphorus. Field evaluations are being conducted across NC to test hybrids made with lines that can potentially perform better in low-phosphorus conditions. By shedding light on how plants have evolved to cope with nutrient limitations, this research will also support the development of more resilient crops with reduced reliance on fertilizers that can potentially harm the environment and public health.

The population genomics of mycotoxin production and developing new biodiversity informatics tools – Ignazio Carbone, Entomology and Plant Pathology

Toxins produced by fungi (mycotoxins) are an enormous problem in agriculture, particularly the toxins produced by *Aspergillus flavus* (aflatoxins), which cause an estimated \$240 million in estimated crop losses annually in the US alone. To address this problem, NC State researchers developed new tools and methodologies to analyze the evolution of myotoxicity and support the development of more cost-effective, sustainable control strategies for mycotoxins. Milestones so far include a recent patent outlining a genetics-based approach to controlling mycotoxin production, which preliminary field studies have already shown to be effective in controlling aflatoxin contamination in maize. Researchers have also developed DeCIFR, a comprehensive suite of tools designed to help researchers discover, analyze, and describe the genetics of plants, animals, fungi, microorganisms, and viruses, empowering NC State students and scientists across

the world to better understand and address biological threats to food security.

Improving management of plant-parasitic nematodes through applied epidemiology – Adrienne Gorny, Entomology and Plant Pathology

Plant-parasitic nematodes (PPN) can cause significant reductions in crop yield and quality, and current knowledge gaps make it challenging for growers to make sound decisions about control strategies. To help close these gaps, NC State researchers conducted surveys to analyze the differing characteristics and population patterns of PPN. Their data was published in an academic journal and provided to vegetable growers, many of whom were not previously aware of potential nematode issues. They also conducted field trials to evaluate the effectiveness of various PPN management strategies. Their data has been provided to growers through Extension and outreach events, used to update agricultural chemical manuals, and used to develop individual management recommendations. In addition, they discovered that planting peanut in plots previously heavily infested with guava root-knot nematode reduced nematode populations significantly more than planting tobacco. These efforts and other ongoing research projects are shedding light on more effective control strategies for a critical emerging agricultural pest.

Maximizing the value of genomic surveillance data for agricultural pathogens – David Rasmussen, Entomology and Plant Pathology

To support growers and other stakeholders in controlling the spread of agricultural pests and diseases, new and improved genetic analysis tools are needed to evaluate these threats and develop targeted control strategies. To this end, NC State researchers have developed and improved new technologies and methods for tracking the spread of pathogens using pathogen genetic data and applied them to the study of important pathogens, including tomato spotted wilt virus, plant-infecting potyviruses, and deformed-wing viruses in honeybees. They also released a new software package (Espalier) that allows researchers to track the exchange of genetic data between pathogens that could lead to the emergence of new and problematic and agricultural pathogens. These efforts will illuminate how pathogens spread and evolve, supporting the resilience of all sectors of the agricultural economy and supporting animal and plant health in general.

Genomic and proteomic breeding in cultivated Virginia-type peanut – Jeffrey Dunne, Crop & Soil Sciences

NC is a major producer of the Virginia-type peanut, which is threatened by a fungal disease called leaf spot. Treatment of this disease often calls for costly fungicide applications that burden growers. NC State researchers are in the process of establishing a more efficient Virginia-type peanut genotyping pipeline that will reduce costs by an estimated 75% compared to the only currently available alternative. This will allow researchers to more quickly develop breeding lines with more desirable traits, including resistance to leaf spot. In addition, NC State continues its excellent record of cultivar development, ensuring that peanut production continually advances in efficiency, profitability, and sustainability.

Intensifying small grains cropping systems for North Carolina for improved yield and quality – Angela Post, Crop & Soil Sciences

Improving grain yields in NC stabilizes the grain supply for animal agriculture and flour production. Over the past five years, NC State researchers have been developing an intensively managed wheat program for small grain growers. In 2023, this program secured additional funds and hosted 19 programs showcasing 56 research trials across NC, educating 744 producers and stakeholders. Actionable insights communicated to growers include applying nitrogen when wheat is planted in the early or middle part of the planting window and the identification of Italian ryegrass as the number one production threat. In addition, new yield data was added to the NC Variety Selection Tool for wheat, and three peer-reviewed articles were published on small grains production in NC. In 2023, the Small Grains Program also proposed an international Extension exchange to learn production practices from other countries, and the first exchange visit is planned for Australia in 2024. The adoption of more intensified wheat production practices has supported an average annual yield increase of 2.6 bushels per acre since 2016, and the NC State Small Grains program continues to support these practices, improving farm incomes and the lives of rural stakeholders.

Improving yield and quality of vegetable crops with improved genetics, fertilization, and stand establishment practices – Jonathan Schultheis, Horticultural Science

Cucurbit crops (e.g., cucumbers, melons, squashes, and gourds) and sweetpotatoes remain important cash crops in NC. Growers need evidence-based guidelines for producing high-yielding, high-quality cucurbit and sweetpotato crops. NC State researchers conducted numerous studies in 2023 to address this need. They identified top-yielding varieties of zucchini under stress from the papaya ringspot virus as well as high-yielding cultivars of standard-sized seedless watermelon, mini seedless watermelon, and canary melon. They also studied the most commonly grown pumpkin cultivar in the US (Kratos), discovering that fruit size increased as spacing between plants increased. When the lowest number of plants per acre studied was used, net returns per acre increased by up to \$7K in comparison to the highest number of plants per acre studied. In addition, they discovered that peanuts and corn were the most effective rotation crops for reducing root knot nematode damage to sweetpotatoes, and fumigation with Telone II enhanced marketable yields when used with peanut and corn crop rotation. These actionable insights will help growers select crop varieties and production practices that limit the impact of pests and disease, securing higher yields and profits.

Gene-specific translation regulation – Jose Alonso, Plant & Microbial Biology

Plant hormones are known to affect many aspects of plant growth and development, as well as their response to environmental changes. Traditionally, these hormone effects have been studied at the levels of changes in the mRNA levels. In this project, researchers studied the effects of these hormones on the levels of protein production. This study not only provides a better understanding of how plants respond to different stimuli mediated by plant hormones but also provides new approaches for plant biotechnology. This research has identified a large number of genes regulated at the translation-efficiency level by auxin. Findings on the unexpected critical role of regulation of translation in the plant responses to hormones are not only changing the way we understand how these growth regulators exert their functions, but are also encouraging researchers in other areas of biology to examine the role of this type of regulation of gene expression in their experimental systems. In addition to disseminating the results from our research in specialized journals and talks at scientific conferences, we also carried out divulgation

activities for the general public. These divulgation activities include online activities for kids through our Plants4Kids program, several educational videos through our YouTube channel, and in-person demos at the North Carolina Science Museum.

Agronomic Crop Production Systems - Cotton. NC State Extension

Cotton is a major cash crop for North Carolina contributing close to \$300 million to North Carolina's economy and 15,000 jobs. Cotton producers often consider variety selection to be among the most important decisions they make. To support variety selection and sustainable growth in cotton production, NC State Extension conducted variety trials and developed innovative products, decision tools, technology, and research-based best management practices. These innovations and practices were transferred by Extension specialists and agents to growers through production meetings, research and demonstration plots, field days, on-farm consultations, websites, and educational media. As a result of the knowledge gained from Extension programs, cotton growers were able to increase yields and decrease production costs. NC State Extension is enhancing agriculture in North Carolina and contributing to the economic well-being of the state.

Agronomic Crop Production Systems - Grains. NC State Extension

Corn, soybeans, and small grains (wheat, barley, or oats) are grown in most North Carolina counties. North Carolina agronomic crop producers planted approximately 4.6 million acres of row crops in 2022, with the highest acreage planted with soybeans, corn, and wheat. Producers face technological, biological, and environmental challenges that impact crop yield and ultimately the profitability of their farm operations. Educating growers on research-based best practices equips them with the knowledge to adopt practices that are correlated with increased yields. NC State Extension grains specialists used applied research and on-farm and official variety testing to develop new varieties, products, technology, and research-based crop best management practices to support growth in corn, soybean, and wheat production and help growers address their technological, biological, and environmental challenges. Extension specialists and agents transferred knowledge of these innovations and practices to producers through Extension publications, websites, meetings, workshops and field days, research and demonstration plots, on-farm consultations, webinars, and videos. As a result of attending Extension events, grains producers have increased revenue by adopting Extension recommended best management practices, including practices that improved nutrient management, natural resource conservation, overall production, cultivar selections, integrated pest management (weeds, diseases, insects), business management, and marketing. Our trusted research-based programs and technical assistance provide solutions and empower clients to make better-informed decisions.

Agronomic Crop Production Systems – Peanuts. NC State Extension

North Carolina is home to over 1,400 peanut farms and ranks 5th in peanut production in the United States, often producing more than 500 million pounds of peanuts per year. Successful production of quality peanuts requires growers to plan an effective production and marketing program and to implement that program on a timely basis during the season. Each practice and marketing decision must be effectively integrated into the total farm management plan to produce optimum profits from the whole farm. NC State Extension peanut specialists used applied research and on-farm and official variety testing to develop new varieties, products, technology, decision-tools, and research-based crop best management practices to support growth in peanut

production and assist growers address their technological, biological, and environmental challenges. New technologies, field trials and producer training has led peanut growers to increase yields and reduce production costs, resulting in stable prices for consumers.

Animal Production Systems - Aquaculture. NC State Extension

Aquaculture is the fastest growing food animal agriculture sector in the world, yet 90% of the seafood consumed in the US is imported, and this has created an annual \$17 billion trade deficit. Several major aquaculture species (e.g., hybrid striped bass, striped bass, white bass) have the potential to provide consumers with a reliable supply of domestic fish, but commercial aquaculture producers need research-based guidance to ensure that North Carolina's aquaculture industry can remain strong and continue expanding. Extension aquaculture programs focused on improving science-based marine fisheries management and farm-raised fisheries. Extension efforts have included providing specialized assistance to address management issues, serving on scientific committees of fisheries management councils/organizations, participating in advisory work to review the scientific basis of fisheries management plans and fishing level recommendations, training fisheries scientists and engaging fishermen in fisheries research and education. Our world-leading faculty and exceptional field faculty are at the forefront of innovation and discovery.

Animal Production Systems - Apiculture. NC State Extension

Bees play a crucial role in the health of local ecosystems. Over \$186 million worth of crops and over 100 crop varieties in North Carolina depend on honey bees for pollination annually, with blueberries, cucumbers, squash, and melons included in the list of honey bee-dependent crops. Members of the NC State Apiculture Program have collectively provided over 180 presentations to local and regional beekeeping groups over the last 3 years, resulting in over 32,000 direct contacts. They have also developed the exciting new Beekeeper Education & Engagement System (BEES), an online learning community for beekeepers that includes multiple mini courses for beekeepers at all levels. NC State also runs the Queen & Disease Clinic to provide beekeepers with tailored diagnostics and recommendations for queen and colony health so that they can make real-time management decisions that affect their operations. Our leadership in experiential education equips clients to effectively transfer knowledge and skills into practical application.

Animal Production Systems - Poultry. NC State Extension

North Carolina is ranked #1 for production of all poultry species. Over 40% of the state's agricultural receipts come from poultry. To support increased profitability of poultry producers, NC State Extension transferred information about innovative products, novel technologies, and best management practices to producers through meetings, workshops, certification programs, on farm consultations, websites, and newsletters. 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 protecting the welfare of flocks and decreasing the environmental impact of their operations. NC State Extension is enhancing agriculture to provide all North Carolinians access to safe, nutritious food.

Animal Production Systems – Waste Management. NC State Extension

Animal waste produced throughout the state must be carefully managed to ensure that the nutrients it contains do not go to waste and that it does not pollute waterways and other natural resources. Extension played a key role in helping animal producers remain in compliance with

waste management regulations, reduce costs and inefficiencies related to waste management challenges, and protect natural resources from waste contamination. Extension conducted 470 on-site surveys of sludge lagoons and equipment calibrations and developed or updated 431 waste utilization and management plans. Extension specialists conducted 21 training events, providing 1,666 contact hours and reaching 690 stakeholders. Extension continues to keep producers up-to-date and protect the environment.

Horticulture Plant Systems – Consumer Horticulture. NC State Extension

NC State Extension provided education to North Carolinians on gardening and lawn care practices that mitigate the negative impacts associated with residential landscapes, such as water quality degradation, reduced biodiversity, and loss of ecosystem services, to preserve the quality-of-life people living in our state expect and rely upon. 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 Master Gardener volunteers dedicated 27,693 service hours to providing research-based advice and recommendations that transform science into everyday solutions for North Carolinians by staffing plant clinics, booths, and infolines at the Extension center and community events. These outreach activities reached over 71,000 community members. As a result of NC State Extension programs, 11,794 individuals started a vegetable and/or fruit garden, and 95,276 participants used Extension-recommended best management practices in landscapes, turf, and gardens, including insect, weed, disease, wildlife and soil management. In addition, 50,078 participants are selecting appropriate landscape plants (adapted, drought tolerant, appropriate size, etc.) after participating in Extension consumer horticulture programs.

Horticulture Plant Systems – Fruit Production. NC State Extension

North Carolina is a lead producer of both tree and small fruits. Horticultural production includes a diverse portfolio of traditional and specialty crops. To meet the challenge of feeding a growing population, research-based horticulture best management practices have been developed and adopted in the production of fruits and nuts and other staple and specialty commodities. NC State Extension delivered research-based knowledge in a variety of formats, having a wide-ranging impact on individuals, families, and industries alike. Workshops, handbooks, newsletters, podcasts, and other resources share our unbiased research on a variety of topics, including composting, ornamentals, fruits, vegetables, specialty crops, organic production, pest management, and more. Our trusted research-based programs and technical assistance provide solutions and empower clients to make better-informed decisions.

Horticulture Plant Systems – Plant Pathology. NC State Extension

Home and commercial horticulture producers must contend with an ever-growing list of complex factors that dictate the success of their crops, including new and emerging pests and diseases. Some of these pathologies have the potential to devastate not only individual growers but also local economies. NC State Extension specialists used applied research, diagnostic testing, and variety performance evaluations to develop innovative products, technology, and research-based horticulture best management practices that support sustainable horticultural production. Extension specialists led applied research efforts to reduce plant diseases and pests through improved crop management, variety selection, and pesticide management. Extension specialists

and agents delivered information on these innovations and practices and promoted the adoption of best management practices through Extension publications, websites, meetings, workshops, seminars/webinars, videos, newsletters, clinics, consultations, community and demonstration gardens, certification programs, and public outreach efforts to support commercial growers, nursery professionals, resident gardeners, and landscape professionals.

Critical Issue 2: Protecting Environmental and Natural Resources

Developing support tools and protocols for increased water resiliency in rural regions – Chad Poole, Biological & Agricultural Engineering

Water-related crop stress is an ongoing challenge for growers that is becoming increasingly urgent due to climate change. In 2023, NC State researchers evaluated 18 corn hybrids and 21 soybean hybrids under water stress (extreme wet, dry, and optimal conditions), leveraging new collaborations utilizing drone technology to capture water-stress data. The research suggests that corn hybrid selection behavior under water stress influences corn grower net revenue by \$18–\$230 per acre, and soybean variety selection under water stress has an estimated economic impact of \$42–\$210 per acre. The data also indicates that simultaneous management of irrigation and drainage throughout the growing season can increase production, fertilizer efficiency, and downstream water quality. These results have been made available to producers, agents, and crop advisers state-wide through Extension trainings, equipping growers with the information they need to select hardy varieties and manage water on their farms.

Quantification of land use effects on soil ecosystem services in depositional landscapes – Matthew Ricker, Crop & Soil Sciences

Floodplain soils can benefit ecosystems by removing nutrients from surface waters if managed correctly. In the Southeastern US, there is great uncertainty as to how much carbon and phosphorus is contained in land along the edges of water bodies. NC State researchers used a soil survey approach to address this uncertainty and improve floodplain maps, identifying priority areas for management and conservation. The findings suggest that urban development may decrease the environmentally protective attributes of forested floodplains in the Southeastern US. Their research also decreased the uncertainty of wetland locations in broadly mapped floodplains from 45% to 20%. Advanced land use planners and conservationists can improve the accuracy and effectiveness of their efforts by using the results of this research to better distinguish between floodplains and wetlands. With applications in conservation, geoscience, forestry, and infrastructure construction planning, the data from this research has been entered into the National Soil Information System for use by the USDA.

Quantifying recreational harvest and improving stock assessment for North Carolina blue crab – Jie Cao, Applied Ecology

Blue crabs are the most valuable commercial seafood in NC, supporting commercial and recreational fisheries along the Atlantic and Gulf coasts. Blue crabs are sensitive to a wide range of environmental factors, but the impacts of these factors are not well known in NC. NC State researchers developed a model that simulates the life cycle of blue crabs under various environmental conditions to quantify the effects of environmental stresses on their population dynamics. The simulations suggest that NC's blue crab population is relatively resilient to predicted climate change, and they provide insights into the potential effects of other

environmental and chemical stressors. This study improves the understanding of how the environment impacts the blue crab population, which will help manage their resources under environmental pressures and rapid urbanization along the coast. The modeling framework developed can also be adapted to predict impacts on other crustacean and fish species.

Fate of phosphorus in soils as impacted by fertilizer chemistry – Aziz Amoozegar, Crop & Soil Sciences

Phosphorus is an essential plant nutrient. Due to the high capacity of most NC soils to fix phosphorus, farmers often over-apply fertilizer to maintain crop production. To increase fertilizer efficiency and reduce over-application, NC State researchers are studying phosphorus transport from various fertilizers. To support this ongoing research, they also developed and applied an innovative new system for evaluating nutrient release and movement through soil (a soil track system) that is much faster than the soil column evaluation method typically used. This system allows side-by-side comparison of different fertilizers, and it can also be adapted to analyze other fertilizer components and forms. Use of this system could lead to the development of more efficient fertilizers, in turn reducing costs for growers and minimizing environmental pollution from fertilizer runoff.

Mitigating nitrogen losses in sustainable agriculture – Alexander Woodley, Crop & Soil Sciences

To limit the effects of climate change, there is a recent large-scale focus on improving the ability of agricultural lands to keep carbon out of the atmosphere. However, agricultural practices are rarely evaluated in light of their release of highly environmentally harmful nitrous oxide (N₂O) emissions, which can cancel out positive carbon outcomes. NC State researchers discovered that two common soil treatments (biochar and poor-quality leaf litter compost) do not appear to increase N₂O emissions on sandy loam soil in the region evaluated (East-Central NC). They also found that a particular emission measurement method (static chambers) may be inaccurate, at least for sandy soils in the Southeastern US. In addition, they discovered that biochar significantly increased corn and sorghum yields. This research has been shared at regional, national, and international conferences, ensuring that stakeholders have crucial information to make informed decisions about sustainable soil management. Farmers also benefit from this research on the viability of adding certain soil treatments to their operations.

The Value of Water Quality Improvements in Urban Streams – Roger von Haefen, Agricultural and Resource Economics

Streams in urbanizing watersheds are threatened by economic development that can lead to excessive sediment erosion and surface runoff. These anthropogenic stressors diminish valuable ecosystem services and result in pervasive degradation commonly referred to as “urban stream syndrome.” Researchers developed an ecological-production framework that translates measurable indicators of stream water quality into ecological endpoints. To illustrate these methods, an application to the Upper Neuse River watershed located in the rapidly developing Triangle region of North Carolina was created. Results suggest that residents are willing to pay roughly \$127 per household and \$54 million in aggregate for water quality improvements resulting from a stylized intervention that increases stream bank canopy cover by 25% and decreases runoff from impervious surfaces, leading to improvements in water quality and ecological

endpoints for local streams. As a result of this research, the general public will have more confidence that regulatory agencies, when promulgating new environmental regulations affecting urban streams, are developing ones where the economic benefits justify the costs.

Environmental and Natural Resources – Pesticide Safety. NC State Extension

There are approximately 25,000 commercial pesticide applicators and 13,000 private pesticide applicators in NC, all of whom must comply with changing regulations to protect the environment, ensure worker safety, and avoid hefty fines. NC State Extension provides homeowners and growers access to education and resources to ensure they can apply pesticides safely and avoid contributing to pesticide pollution. This year Extension continued to provide a broad range of pesticide training and education for professionals, including assistance provided through nearly 100 pesticide coordinators, pesticide schools, manuals, and factsheets on pesticide licensing, registrations, labels, and safe handling procedures. Extension also supported local communities in keeping pesticides out of waterways and other natural resources by directing pesticide container recycling and disposal assistance programs.

Environmental and Natural Resources – PFAS. NC State Extension

In 2016, NC State and EPA scientists reported the presence of high concentrations of perfluorinated compounds in North Carolina's Cape Fear River and its watershed, and in the drinking water supply of more than 200,000 North Carolinians. Trace organic contaminants, such as per- and polyfluoroalkyl substances (PFAS), can have negative impacts on human and animal health. Understanding these processes at the fundamental level is critical and broadly applicable to a number of environmental and agronomic areas. Scientists at NC State University have studied the way plants and microbes acquire metals and PFAS in soils and aquatic environments. We have developed new methods of quantifying molecules released by plants and microbes to facilitate metal acquisition and are working to understand and model how these molecules function in soils and sediments. Through integrated research and extension activities, NC State is contributing to protecting the health and wellbeing of the public, our water, livestock, and agricultural products.

Environmental and Natural Resources – Saltwater Intrusion. NC State Extension

Climate change is causing sea level rise and increased flooding that threatens North Carolina's most fertile agricultural land with saltwater intrusion. Some of the most agriculturally productive lands in North Carolina are found along the coast, but a rising tide threatens the future of the region. More saltwater is intruding on farmland and becoming saltier; salinity levels in some areas have doubled since the 1980s. Saltwater intrusion damages crops by compromising soil fertility with elevated soluble salt levels that can be toxic to plants. As a result, farmers are experiencing huge economic losses. NC State is studying the impact of soil salinization on farms and the carbon sequestration capacity of the land. The goal is to recommend management options for farmers to adapt to climate change in the coming decades. Our world-leading faculty and exceptional field faculty and staff — who are at the forefront of innovation and discovery — provide high-tech, high-touch expertise to serve the unique needs of diverse clients.

Critical Issue 3: Enhancing Food Safety, Nutrition and Health

Adding value to oysters through the utilization of electrolyzed water as a post-harvest processing technique – Alexander Chouljenko, Food, Bioprocessing, and Nutrition Sciences

Vibrio bacteria in oysters pose a significant threat to public health, contributing to serious seafood-borne illnesses across the US. Although current FDA-approved post-harvest treatments effectively reduce *Vibrio* levels, these treatments are rarely adopted because they negatively affect the texture and taste of oysters while demanding high financial and logistical costs. To address this challenge, NC State researchers conducted experiments to determine if electrolyzed water (EW) can provide a cost-efficient, environmentally friendly antimicrobial treatment. Their research demonstrates that sequential applications of alkaline and acidic EW reduced populations of non-disease-causing *E. coli* bacteria to undetectable levels. This finding establishes a strong foundation for future studies on the use of EW to eliminate food-borne pathogens. This research has been submitted for presentation at the 2024 International Association for Food Protection (IAFP) Conference. Ultimately, this ongoing research supports public health and the food industry by outlining a scalable, sustainable, and environmentally friendly solution to reduce foodborne illness.

Advanced Thermal and Continuous Microwave Processing of Foods and Biomaterials – Josip Simunovic, Food, Bioprocessing, and Nutrition Sciences

To optimize the efficiency of food production and minimize waste, innovation is needed to create more advanced food technologies that can maximize retention of nutrients and flavors. Thanks to NC State research, for over 15 years, Yamco, LLC has been using a continuous flow microwave processing technology to make sweetpotato, fruit and vegetable puree ingredients used in over 100 new products. SinnovaTek, Inc. and FirstWave Innovations have implemented NC State's licensed microwave processing technologies to produce new nutrient-dense retail foods. The Burton and Bamber/Sweetunda Factory in Nairobi, Kenya is using the same processing technology to make shelf-stable sweetpotato purees, which are used to enrich bakery products with beta-carotene to help prevent childhood blindness. These purees were recently highlighted by the Bill and Melinda Gates Foundation at the UN Climate Change Conference, and they are currently considered for use by the UN/US World Food Programme. Previously, sweetpotato farmers in NC lost up to 40% of their crops due to imperfections, but the ability to create shelf-stable purees eliminates this massive waste. Since NC State's microwave processing technology was introduced, NC sweetpotato production has risen from 32% to 60% of the nation's production, which has doubled over the same period.

Mechanisms by which interactions between dietary phytochemicals and the gut microbiome influence chronic disease risk – Andrew Neilson, Food, Bioprocessing, and Nutrition Sciences

Phytochemicals are compounds found in plant foods that may support human health and reduce the risk of chronic disease, but there is limited understanding of the relationship among phytochemicals, gut bacteria, and disease risk. NC State researchers studied phytochemical-rich foods such as blueberries, cocoa, tea, and artichokes, developing and applying a fermentation model using human fecal samples to study whether these foods and their phytochemicals can limit gut bacteria's production of trimethylamine, a chemical known to play a role in the development of cardiovascular disease and other illnesses. Lowering the production of trimethylamine could be a

strategy for reducing cardiovascular disease rates. Through these studies, researchers discovered that blueberries, cocoa, and artichokes are potent trimethylamine-lowering foods. The research findings were communicated through peer-reviewed journal articles and presentations at international research conferences. This research contributes to a growing body of knowledge about how plant foods can reduce the risk of chronic and life-threatening illness.

Food Safety – Home Food Preservation. NC State Extension

Home food preservation continues to be an area of interest for North Carolinians wanting to take advantage of the abundance of available foods from home gardens and local markets. However, food preservation is a science-based practice, and testing the safety of recipes can only be conducted in a lab with special equipment and trained food scientists. To reduce instances of foodborne illness, NC State Extension developed resources and provided training on food preparation and food safety. Extension's efforts 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. As a result of attending Extension programs, 141,758 participants increased their knowledge of safe home food handling, preservation, and preparation practices. Our leadership in experiential education equips clients to effectively transfer knowledge and skills into practical application.

Food Safety – Safe Plates. NC State Extension

Despite food safety communication efforts by many sectors, foodborne illness remains a significant health issue in North Carolina and across the country. 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. To reduce instances of foodborne illness, NC State Extension developed resources and provided training on food preparation and food safety. Extension provided NC Safe Plates training to food service employees and managers to ensure safe handling of food at retail establishments and prevent outbreaks of foodborne illness. As a result of this training 3,193 food handlers increased their knowledge and skills in safe food handling practices.

Nutrition & Health – EFNEP. NC State Extension

Many limited-resource families struggle with food resource management, food security, meeting the nutritional needs of their family, and keeping food safe to eat. To address chronic disease risk and food insecurity, NC State Extension's Expanded Food & Nutrition Education Program (EFNEP) offers free nutrition classes in 40 NC counties to help families and youth cook healthy meals at home, be more active, save money on food costs, and handle food safely. EFNEP helps address the challenges limited-resource families face by introducing healthy changes through nutrition education, cooking classes, physical activity strategies, and shopping on a limited budget. During 2023 1,826 families enrolled in EFNEP, and 20,043 youth participated in 4-H EFNEP. As a result of EFNEP activities, 98% of EFNEP participants improved diet quality and 96% of participants improved their food resource management skills.

Nutrition & Health – Steps to Health. NC State Extension

The NC Steps to Health program provides a comprehensive approach that impacts the health and nutrition of limited-resource residents by not only providing Extension-delivered direct education to food-insecure families and youth but also promoting systematic community changes to support

healthy living. Steps to Health is dedicated to inspiring healthier communities by shaping the environments where individuals with limited incomes buy, cook, consume, and enjoy food. As a result of the Steps to Health program, 117,342 persons were impacted through food and built environment efforts to increase healthy food options and physical activity, and 3,745 participants were enrolled in nutrition education programs.

Critical Issue 4: Enriching Youth, Family & Community Well-Being

Farm and farm household well-being among NC pasture-based dairy and hog producers – Michael Schulman, Agricultural and Human Sciences

COVID-19 created new challenges that disproportionately affect small-scale producers; these issues further burden Black farmers already coping with chronic stress due to discrimination and social isolation. In collaboration with Rural Advancement International and the NC Agromedicine Institute, NC State researchers surveyed 15 Black and 15 white farmers and analyzed their responses to determine how they navigate financial crises and emotional stress. Researchers identified many recommendations for service provision, including adoption of a team-based/networking approach, identifying and strengthening farmer-to-farmer and farmer-led organizations, expanding financial and mental health services for small-scale farmers and their families, and developing an accessible, comprehensive farm and household management toolbox, with a focus on mitigating financial and emotional stress. Given concerns about discrimination from public agencies, the need to develop informal and community networks to support Black farmers is particularly urgent. These recommendations have been shared with professional and community organizations, a brief on farmer stress was published through the FARSAN-South network, and a recent article was published in the Journal of Agromedicine.

Using a consumption-oriented supply chain analysis to increase consumer access to local food – J. Dara Bloom, Agricultural and Human Sciences

Sixty percent of American children under the age of six are enrolled in child care programs, where they spend an average of 27 hours a week and consume a significant portion of their daily food intake. By integrating local foods into experiential learning activities, the Farm to Early Care and Education (ECE) program plays an important role in child health, but it faces many logistical challenges. NC State researchers studied three local food procurement strategies to address this issue, and their initial findings suggest it is possible to design an ECE model that is easy for providers to use while increasing the market for local foods. This research also identifies key logistical factors for success (e.g., Monday ordering, offering multiple purchasing methods) and pinpoints the most important ongoing challenges. The findings of this ongoing research are shared in real time with communities, supporting increased stakeholder reach, increasing local food purchasing, supporting other vulnerable populations (including seniors and food-insecure households), and increasing revenue for farmers and food hubs.

4-H Youth Development – Agriculture Education. NC State Extension

To support future agricultural needs, there is an urgent need to educate youth on food production and to increase interest in careers in agriculture. 4-H provided opportunities for youth to increase their awareness of agriculture through school-based programs. In addition, the NC 4-H Horse Program, Dairy Youth Program, Poultry Youth Program, and 4-H Youth Livestock Program provide additional opportunities for you to learn about caring for animals. As a result of 4-H programs, over

93,000 youth enhanced their knowledge of animals and agriculture, and nearly 70,000 youth enhanced their knowledge of biological sciences or plant sciences.

4-H Youth Development – Civic Engagement. NC State Extension

4-H helps youth ages five to 18 identify their passions and develop life-skills, including instilling a sense of civic engagement. 4-H civic engagement programs empower youth to become well-informed citizens who are actively engaged in their communities and the world. Through these programs, youth learn about civic affairs, build decision-making skills, and develop a sense of understanding and confidence in relating and connecting to other people. As a result of 4-H programs, over 12,000 youth enhanced their knowledge of civic engagement, community, or volunteer service, and over 17,000 youth enhanced their knowledge of leadership and personal development.

4-H Youth Development – Cooking Skills. NC State Extension

Poor nutrition and obesity in childhood have been linked with obesity and other chronic diseases in adulthood. Physical activity practices, eating habits, and behavior patterns established during childhood persist through adulthood. Young people with proficient cooking skills are more likely to eat nutritious meals and lead healthier lifestyles. NC State Extension provided youth with opportunities to learn what a nutritious diet consists of as well as the chance to develop the skills necessary to prepare nutritious meals to help establish healthy eating habits and lifelong behavior patterns. North Carolina State University implemented and hosted the Dinah Gore 4-H Healthy Food Challenge. Young people formed teams and participated in a healthy living food challenge competition at the district and state levels as well as a team representing North Carolina in the national competition. This contest challenged teams of three to four 4-H members to create a dish using only a predetermined set of ingredients. From these ingredients, team members identified and prepared the dish, then made a presentation to the judges covering their dish, its health benefits, and the nutrients that the dish provides to the body. As a result of Extension programs, 27,527 youth enhanced their knowledge of health, 80,792 youth increased fruit and vegetable consumption, and 17,928 youth increased their physical activity level.

4-H Youth Development – SPIN Clubs. NC State Extension

In 2023, over 19,000 North Carolina youth participated in 4-H clubs. Assisting with the operation of these clubs were over 11,000 volunteers donating 99,923 hours valued at nearly \$3M. These volunteers provided opportunities for youth to work and learn in partnership with caring adults. Traditionally, 4-H clubs last for a semester or for a year, but 4-H also provides special interest (SPIN) clubs that cover several topics over the course of six months, providing youth with an opportunity to explore something new while recruiting new members and testing out new topics for potential introduction to longer-term clubs. Topics offered by SPIN clubs included mindfulness, agriculture, sewing, food and nutrition, cooking, creative arts, information technology, beekeeping, and more.

4-H Youth Development – Environmental Education. NC State Extension

The Wildlife Habitat Education Program (WHEP) is a youth natural resource educational program dedicated to teaching wildlife and fisheries habitat management to youth. WHEP brings 4-Hers together to develop team skills, promotes and develops leadership skills among 4-Hers, and provides an opportunity for 4-Hers to work with natural resource professionals. The 4-H Forestry

Contest helps develop appreciation for the importance of conserving forestland as a source of products, benefits, and services necessary for quality living. 4-H foresters learn practical forest management skills through participation in the 4-H Forestry Contest. Learning these skills will help our leaders of tomorrow be prepared to own forestland or deal with environmental issues in the future. As a result of 4-H youth programs, over 52,000 youth enhanced their knowledge of environmental education.

4-H Youth Development – Winged Wonders. NC State Extension

School enrichment refers to the process of enhancing the educational experience within a school environment by providing additional learning opportunities, activities, and resources beyond the standard curriculum. Through the 4-H Winged Wonders curriculum for youth ages 6-8, youth observe the wonders of the natural world unfolding in front of them by raising painted lady butterflies from larva through adulthood. Youth experience the mystery of the butterfly life cycle while engaging in hands-on activities that explore concepts of insect structures and functions, compare insect behaviors and life cycles, and demonstrate the role everyone can play in environmental stewardship and pollinator habitat protection. The Winged Wonders program was offered in 25 North Carolina counties, reaching over 6,750 youth.

Families and Communities – Food Security

Extension continued partnering with diverse community organizations to increase public access to healthy, nutritious, and affordable meals and provide residents with the knowledge and skills needed to nurture their families. Thanks to Extension efforts in 2023, 3,907,670 pounds of local food were donated to vulnerable populations, 5,876 food insecure households received emergency food assistance, 8,262 individuals gained knowledge and/or skills to increase family economic security (e.g., accessing SNAP benefits, food cost management), 2,678 individuals accessed programs and implementation strategies to support family economic wellbeing, and 9,982 youth grew produce by participating in Extension organized school and home garden programs.

Economic Development – Rural Development

Given the rising consumer interest in local foods and smaller-scale farming, individuals looking to start small farms need support to make their farms successful and profitable. To meet this need, Extension offered an eight-session NC Farm School course across six counties. Extension also launched the Small Farm Boot Camp pilot program as a resource for small-scale farmers & producers who are beginning a business. Extension partnered with the Career Skills Program on Fort Liberty to provide soldiers who are transitioning out of the military the opportunity to participate in a Soldier to Agriculture Program. The soldiers learned about working in the agricultural industry. As North Carolina's first registered agricultural apprenticeship program for military veterans, Boots on the Ground: NC Veteran Farmer Apprenticeship aims to increase the pool of trained agricultural workers for management and entrepreneurial positions at farming operations in North Carolina. Our extensive partnerships with agriculture, business, industry, education and government create a unique culture of collaboration that increases productivity and fuels economic development.

Community Development – Serving Diverse Audiences

North Carolina is changing rapidly. Changes in state demographics, shifts in living patterns, and the influx of migrant workers create a need for health and safety education as well as financial literacy and planning. NC State Extension's Farmworkers Health and Safety Program provided 97 on-farm training sessions to 3,437 farmworkers. Extension also provided vaccination education for farmworkers and their families to increase their trust, knowledge, and positive perception of vaccination as a way to protect their family's health. A Spanish Language Pesticide Applicator School was established to provide training to non-English speaking applicators. Extension also hosted several outreach events to engage diverse populations. Our world-leading faculty and exceptional field faculty and staff — who are at the forefront of innovation and discovery — provide high-tech, high-touch expertise to serve the unique needs of diverse clients.

Infrastructure Development – Digital Skills Education

As technology has become an integral part of our daily lives, older adults tend to lack the knowledge and skill to utilize certain technology that could be beneficial to them. It is critical for older adults to learn how to utilize technology and how to navigate the online world without the fear of being scammed, being a burden to their younger family members, or receiving misinformation. There are also youth, farmers, and other members of the community who lack necessary digital skills. NC State Extension helped strengthen NC's infrastructure and resilience to build on technological opportunity and address demographic changes, workforce health and safety issues, and consumer demands to build the future economic, health, and social well-being of NC communities through a digital skills education program.

Local Food Systems

Resilient localized food systems ensure a continual supply of safe, accessible food while supporting the economic vitality of farms of all sizes. NC State Extension has educated consumers about the importance and significance of agriculture and its importance to the continued growth of the local food economy. As a result of Extension efforts, engagement with local food systems has increased grower profits, supported our agricultural economy, and provided critical education and awareness to the public regarding the importance of agriculture. As a result of Extension efforts, 47,703 individuals intend to use local foods when cooking, preparing or preserving foods, 486 new or existing local food access points are available to consumers, and 294 local food value chain businesses were supported by programs or technical assistance.