Critical Issue: Improving Plant and Animal Agricultural Systems

Agronomic Crop Production Systems. NC State Extension

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.

Extension agents delivered close to 2,000 in-person and virtual training sessions to over 40,000 growers on agronomic crops, and over 13,000 additional growers attended training provided by Extension specialists. Over 15,000 pesticide applicators received continuing education credits. Nearly 200,000 growers were provided with technical assistance. NC State Extension is enhancing agriculture in North Carolina that supports thriving communities and provides all North Carolinians access to safe, nutritious food.

Animal Production Systems. NC State Extension

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 development 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.

As a result of NC State Extension educational programs and technical assistance, 6,975 producers increased knowledge of pasture/forage management practices, 4,614 producers increased their knowledge of nutrition and breeding, and 5,033 producers increased knowledge of strategies for promoting animal health and welfare.

Horticulture Plant Systems. NC State Extension
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 NC State Extension programs, over 425,000 participants gained knowledge of landscape, turf, and garden best management practices, including pest and soil management. Over 100,000 participants use Extension-recommended best management practices in landscapes, turf, and gardens; and nearly 55,000 participants selected appropriate landscape plants after participating in Extension consumer horticulture programs. Because 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.

Developing New and Emerging Horticultural Crops and Improving Organic and Sustainable Vegetable Production. Jeanine Davis
DELIVERED INSIGHTS AND NEW VARIETIES TO ENHANCE SPECIALTY CROP PRODUCTION: To help keep agriculture profitable in NC, growers need improved varieties and assistance producing new high-value crops. To strengthen the diversity, sustainability, and profitability of agriculture in NC and throughout the Southeastern US, NC State researchers are conducting research and field trials and providing education to ensure growers are prepared to take advantage of growing consumer demand for specialty crops. Milestones to date include breeding and testing new hop varieties specialized for production in the warmer, wetter conditions often found in southern latitudes; creating efficient, reliable production systems for forest botanicals and educating growers to accommodate a growing consumer interest in medicinal herbs; and completing variety trials and testing drying strategies to help farmers produce high yields of quality floral hemp. NC State researchers have also collaborated with Cornell University and private breeders to develop and test new broccoli breeding lines in an effort to create a year-round supply of this valuable, in-demand crop grown exclusively in the Eastern US. In addition, NC State is collaborating on a national project to breed and test new tomato varieties for organic production. The results of this research are shared with growers and the general public through conferences, workshops, and social media outreach.

Developing context-driven decision-support framework to improve region-scale management of animal byproducts. Mahmoud Sharara
ENHANCED SUSTAINABLE, PROFITABLE MANAGEMENT OF ANIMAL BYPRODUCTS: Animal production creates large amounts of waste that can damage the environment and create significant hazards and financial burdens for farmers. To help farmers run more profitable, sustainable animal production operations, NC State researchers have discovered new ways to use animal manure and other animal production byproducts. Milestones include the publication of a study detailing the use of swine lagoon sludge to create low-cost compost materials, presentation of a preliminary study into full-scale greenhouse

systems for processing lagoon sludge into a compact and exportable form, a virtual tour and learning aid to help stakeholders understand and adopt this greenhouse sludge drying technology, and the development of a simulation tool to help predict impacts of future climate conditions on animal production lagoons and storage ponds. These insights and practical tools are a critical means for farmers to minimize environment-related hazards and the environmental impact of their operations while also enjoying reduced fertilization costs.

Development of sensor technology for the early detection of plant disease. Ralph Dean
DESIGNED AND ENHANCED ELECTRONIC SENSOR FOR EARLY DISEASE DETECTION IN CROPS: Crop losses due to pests and pathogens remain a major threat to food safety and security. To address this problem, NC State researchers are working to provide a remote, autonomous, networkable early disease detection platform that will enable more timely and effective disease management in order to increase crop yields. Researchers have designed and refined an electronic sensor that can detect different types of volatile organic compounds (VOCs), substances that plants release when they are stressed due to damage or disease. They have also enhanced this sensor's ability to detect different classes of VOCs and developed computer analyses and deep learning algorithms to further decode these VOC signatures. Interpreting these signatures can help identify the type of pathogen or pest that is damaging plants, potentially even before symptoms appear. This ability to detect pathogens and diseases early will be of major benefit to farmers and consumers by reducing crop losses, limiting the need for chemical pesticides, and reducing labor costs associated with pest and disease control.

Ecological and Biotech-Based Approaches to Control Insect Vector-Borne Plant Virus Diseases. Dorith Rotenberg
DEVELOPED NEW INSIGHTS, TOOLS, AND APPROACHES FOR PREVENTING THE SPREAD OF HIGHLY DAMAGING PLANT VIRUSES: Insect-transmitted plant diseases cause crippling monetary losses to US and global economies. To reduce these losses, NC State researchers are working to develop new, effective, and sustainable ways to control insect-transmitted plant viruses. The milestones they have achieved so far include the development and testing of tomato plants with the genetic ability to neutralize an important genus of viruses (orthotospoviruses), the identification of proteins found in the gut and salivary glands of insects involved in viral transmission (including transmission of the tomato spotted wilt virus, one of the most destructive crop viruses in the world), and the development of new tools that will support analyzing and engineering insect genes in order to naturally suppress their ability to transmit harmful viruses to plants. These insights represent the groundwork for new approaches to enhancing food security and safety, and they have already led to new collaborations with an NC State tomato breeder to incorporate viral resistance into tomato breeding lines, new biotech-based tools for plant gene modification and the study of field-level disease outbreaks, and numerous peer-reviewed publications.

Evaluation of Laying Hen Performance, Welfare, Economic Return, and Egg Quality and Safety for Sustainability and Maximization of Returns. Kenneth Anderson
DELIVERED TOOLS AND INSIGHTS TO ENHANCE POULTRY PRODUCTION SUSTAINABILITY, PROFITABILITY, AND SAFETY: Outbreaks of highly pathogenic avian influenza (HPAI), the increase in consumer demand for sustainably produced eggs and egg products, and the shift from cage to cage-free poultry production have created new challenges for the industry. To address these issues, NC State researchers have studied methods for rapidly and humanely depopulating diseased poultry flocks and have provided new tools, including an improved ventilation shutdown process that more rapidly depopulates diseased flocks, leading to reduced flock distress. This process has been shared with industry and used

extensively by USDA-APHIS incident commanders in 2022 to control the most recent HPAI outbreak. Researchers have also provided data-driven insights for enhancing professional training for poultry producers to improve flock health and welfare, and they are working to understand the impact of cage-free production on egg production and quality, with a focus on helping breeders evaluate their selection strategies and helping producers enhance or modify their approaches. They have also advanced knowledge of methods for recapturing nutrients previously destined for the landfill and repurposing them as alternative feed ingredients to significantly reduce the carbon footprint of poultry production.

Enhancing Poultry Production Systems through Emerging Technologies and Husbandry Practices. Lingjuan Li
LAID GROUNDWORK FOR COST-EFFECTIVE, RESILIENT METHODS FOR REDUCING HEAT STRESS IN POULTRY: Most US broilers are produced in southeastern states where climate change increases the incidence and severity of heat waves, compromising broiler performance and welfare. To develop transformative solutions for broiler industry sustainability, NC State researchers have conducted an assessment of the environmental factors impacting broiler behavior and welfare, advancing the understanding of how a technology called a high air velocity system can help birds regulate their body temperature under hot and humid conditions by releasing excessive heat into the surrounding environment. They also gained insights that will inform the optimal engineering design of a cost-effective air velocity enhancement system for reducing heat stress in flocks without significantly modifying current production structures. This research will not only improve the climate change resilience of poultry production operations but also enhance animal wellbeing, and it may eventually inform artificial intelligence (AI)-powered control strategies for environmental control in animal production. The research results have been disseminated through peer-reviewed publications, a conference report, and specialized training for students.

Genomic and Proteomic Breeding in Cultivated Virginia-type Peanut. Jeffrey Dunne
DEVELOPED NEW CULTIVARS AND GENOTYPING APPROACHES FOR DISEASE RESISTANCE IN PEANUTS: Peanuts are an important source of edible oil and protein in over 100 countries. But peanut breeders face major challenges associated with a lack of genetic diversity that leaves peanut crops especially vulnerable to evolving pests and environmental changes. NC State researchers are using cutting-edge molecular breeding technology to create better tasting peanut varieties resistant to environmental stresses like drought and disease. NC State has already released the highly successful Bailey and Bailey II varieties with built-in resistance to the highly damaging early leaf spot disease. They are currently developing an efficient pipeline for analyzing and improving peanut cultivars for the Virginia-Carolinas region. Once established, this pipeline will make it easier for researchers to map and select beneficial breeding lines, and it will reduce genotyping costs by an estimated 75% compared to the currently available alternative method. They are also working to fortify the Bailey cultivar with genetic resistance to late leaf spot, a common, fast-moving disease that costs growers an estimated $53 million annually.

Improving management of plant-parasitic nematodes through applied epidemiology. Adrienne Gorny
IDENTIFIED MORE EFFECTIVE APPROACHES TO CONTROLLING PLANT-PARASITIC NEMATODES: Plant-parasitic nematodes (PPN) are soilborne plant pathogens that can cause significant reductions in crop yield and quality, and controlling them often demands the use of expensive, time consuming, and environmentally damaging methods. To close current knowledge gaps and support optimized management of PPN, NC State researchers are investigating nematodes' biological characteristics, modeling crop losses in relation to PPN

populations, and evaluating management methods. Through these studies, they have identified new relationships between PPN species and certain weed species and identified a new method for highly accurate detection of a high-impact emerging PPN species (the guava-root nematode). They have also developed and presented new PPN management recommendations at Extension and outreach events, through updates to agricultural chemical manuals, and through individual management recommendations. By supporting effective management of this potentially devastating crop pest, these insights benefit not only the scientific and agricultural communities but also the national food supply and consumers as a whole.

Management of Arthropood Pests on Tree Fruits and Vegetables in North Carolina. James Walgenbach
DISCOVERED NEW INSIGHTS FOR SAFELY CONTROLLING KEY FRUIT AND VEGETABLE PESTS: The brown marmorated stink bug (BMSB) and western flower thrips (WFT) are important pests of fruit and vegetable crops in North Carolina. Current management practices are either ineffective or rely on excessive pesticide use that represents a hazard to farm workers and the environment. To address this challenge, NC State researchers conducted studies to determine the population distribution of the BMSB in NC and established an effective model to predict BMSB population development, providing growers with a new tool for precisely timing insecticide applications for maximum efficiency. Additional experiments revealed that WFT populations in the Piedmont are highly resistant to spinetoram (Radiant), the most effective insecticide against WFT, alerting growers in this region to take alternative measures. The researchers also identified several promising new and experimental insecticides for controlling key pests of fruiting vegetables, apples, and peaches. By helping growers reduce the environmental impact of pesticides and ensure a plentiful, safe, and inexpensive food supply, these studies not only benefit commercial producers but also Extension personnel, the crop protection industry, and the general population.

Phylodynamics of emerging plant pathogens. David Rasmussen
DEVELOPED NEW TOOLS AND APPROACHES FOR UNDERSTANDING AND CONTROLLING PLANT AND HUMAN DISEASE: The continued emergence and spread of agricultural pathogens pose a major threat to agriculture. To enhance understanding of how new pathogens emerge and inform effective control and prevention strategies, NC State researchers are developing new statistical and computational methods for tracking the spread and evolution of plant pathogens using pathogen gene data. Over the past year, they have extended existing methods to meet several challenges posed by agricultural pathogens, including development of improved models for tracking the spread of plant diseases through complex agricultural landscapes, improved methods for tracking exchange of genetic material between different pathogen lineages, and improved methods for analyzing the effects of mutations and other genetic changes on pathogen spread. In addition to informing disease control in agriculture, these models and methods are increasingly being used to gain insights into human pathogens such as influenza, dengue viruses, and HIV, including the identification of major sources and drivers of disease transmission that can be efficiently targeted to support disease control. These findings have been shared through peer-reviewed publications and via high-quality, clearly documented open-source software for the analysis of pathogen genetic data.

Population Biology and Evolutionary History of Phytophthora species on Solanaceous Crops. Jean Ristaino
DEVELOPED AND DEPLOYED TECHNOLOGY TO IMPROVE PREDICTION OF EMERGING PLANT DISEASES: The genus Phytophthora contains many destructive plant pathogens with great impact on agriculture, and Phytophthora plant species represent a significant emerging threat due to increases in plant movement via international trade. There is also the potential for

the emergence of new harmful species through evolutionary change. NC State researchers are developing improved detection and surveillance technologies and tools to better understand and manage new species and react more rapidly to new pathogens. Their accomplishments so far include developing smart phone-based assays and a phone app for rapid in-field detection of emerging potentially harmful species; enhancement and reconfiguration of a disease surveillance, mapping, and grower alert system called USAblight.org; ongoing development of an interactive dashboard to display blight data in near real-time; genetic sequencing and evolutionary analysis of species affecting food, forest, and ornamental crops; and development and deployment of a database and web tool that can be used by the research community to identify and classify new species. Adoption of these new technologies and tools will help scientists, growers, Extension specialists, and other stakeholders respond to the spread of plant diseases with increased precision and speed.

Sustainable Solutions to Problems Affecting Bee Health. David Tarpy
DELIVERED TRAINING, DATA, AND RESEARCH TO SUPPORT HONEY BEE HEALTH AND PRODUCTIVITY: Honey bees play a critical role in agriculture, providing pollination to support approximately one third of our daily food supply, especially the fruits, vegetables, and nuts included in a healthy diet. To protect honey bee populations, NC State researchers are evaluating how various stressors—such as pests, diseases, pesticide exposure, and other environmental factors—affect the survival, health, and productivity of honey bee colonies and pollinator communities. They are also facilitating the development of honey bee stock selection, maintenance, and production programs that promote genetic diversity and pest and disease resistance. Notably, they have addressed systemic problems with honey bee queen health by teaching beekeepers, especially queen producers, to better measure and enhance the reproductive quality of their queens through the Queen & Disease Clinic, generated the largest dataset of honey bee viruses to date to improve identification and management of viral disease in colonies, and provided new insights into commercial queen breeding and the effects of genetic diversity on colony health and productivity.

The Population Genomics of Mycotoxin Production and Developing New Biodiversity Informatics Tools. Ignazio Carbone
DEVELOPED NEW TOOLS FOR REDUCING CROP LOSS FROM HIGHLY DAMAGING FUNGAL TOXINS: Toxins produced by fungi (mycotoxins) are an enormous problem in agriculture, particularly the aflatoxins produced by *Aspergillus flavus*. Direct losses due to aflatoxins are estimated at $240 million annually in the United States alone. NC State researchers are working to characterize the complex biological and environmental factors in agricultural ecosystems that impact mycotoxin production in order to develop more cost-effective, sustainable control strategies. They are also developing advanced tools to accelerate understanding of how naturally occurring organisms and substances can be used to combat mycotoxins, including a comprehensive, publicly available web-based toolkit called DeCIFR that enhances the efficiency of evolutionary and ecological studies. These tools have supported the publication of 16 scientific papers and the delivery of key insights into how growers can reduce aflatoxin contamination in NC.

Translational approaches to improve management strategies for cucurbit and sweetpotato diseases in North Carolina. Lina Quesada
DELIVERED HIGH-IMPACT APPROACHES AND TOOLS FOR MANAGING DISEASE IN SWEET POTATO AND GOURD CROPS: Vegetables are important crops in North Carolina, with a farm gate value of over $2 billion. Plant diseases limit vegetable production and quality and, in some cases, threaten the survival of the industry. To address these threats, NC State researchers are studying diseases of sweet potato and cucurbits (the gourd family, which

includes cucumbers). To date, they have partnered with growers, packers, Extension agents, and industry stakeholders, developed a field biosurveillance system, and supported the release of new cucumber varieties to drive effective, precise management of the devastating disease cucurbit downy mildew. They have also established strong collaborations with chemical companies and the USDA's IR-4 project to secure registration for five new fungicides to combat the epidemic of sweet potato black rot, reducing disease losses from 40% to 5% and preventing an estimated $116 million in losses for NC growers. They are currently working to reduce trade barriers to sweet potato exports and have already collaboratively secured a $1.5 million grant to continue expanding NC sweet potato exports while safely and effectively controlling post-harvest disease. Their efforts have also reduced the need for fungicide sprays, saving NC growers approximately $2.5 to $6 million annually. This research has been shared through websites, social media, presentations to growers and academics, and peer-reviewed articles, benefitting not only NC growers and consumers but also the global supply of these important crops.

Turfgrass Breeding and Genetics. Susana Milla-Lewis
RELEASED NEW CULTIVARS AND PROVIDED RESEARCH INSIGHTS TO STRENGTHEN NC TURFGRASSES: Turfgrass plays an important economic role in several industries, providing ground cover for homes, roadsides, parks, commercial properties, sports fields, and more. North Carolina is located in the transition zone for cool- and warm-season grasses. Although this means that we can grow both types of grasses, no one type of grass does well in all weather conditions. In addition, the turfgrass industry loses about $300 million annually to pests and environmental stresses. To address these challenges, NC State researchers have developed new turfgrass varieties, including Lobo—a robust, groundbreaking cultivar suitable for use in lawns, roadsides, and golf courses that boasts both reduced water requirements and improved cold resistance—and Sola, an improvement on a long-standing variety produced earlier by NC State, which offers aggressive growth, shade and drought tolerance, better resistance to chinch bugs and gray leaf spot, and superior sod strength. In addition to releasing new grasses that save money for consumers and industry, NC State's turfgrass breeding program delivers data and insights that help turfgrass breeders and geneticists increase selection efficiency in the US and internationally.

Understanding how symbiotic fungi affect plant productivity and stress resilience across scales. Christine Hawkes
DELIVERED KEY INSIGHTS INTO HOW BACTERIA AND FUNGI AFFECT PLANT HEALTH: The plant microbiome is the community of microorganisms that live in and on plants. This microbiome is critical to preserving the productivity and safety of the agricultural food supply because it can change how plants grow, access nutrients, and tolerate stress. As stressors such as drought and disease continue to reduce crop yields and fertilizer costs rise, the microbiome can provide alternative approaches to sustainable agricultural management. NC State researchers have analyzed microbiomes associated with switchgrass leaves, roots, and soil across the state to determine why they occur where they do; characterized fungi associated with four wheat cultivars and surrounding vegetation to identify sources of the wheat microbiome; tested how microorganisms living inside plant leaves affect disease resistance in wheat and corn; and examined how microorganisms living inside plant roots affect switchgrass crops' access to organic nutrients. To date, they have identified key environmental and biological controllers of microbiome community assembly at the local and regional levels, and they are beginning to identify the mechanisms that determine how fungi interact with plants to affect stress and disease resistance. They have also suggested new potential avenues for improving plant nutrition in agriculture without increasing the use of commercial fertilizers. Overall, their findings suggest several novel strategies for improved management of agricultural

ecosystems via plant and soil microbiomes. This research has been shared through student training, in peer-reviewed publications, and in academic presentations. By laying the groundwork for new, sustainable approaches to crop management, this research will support a more affordable, secure, and productive food supply.

Critical Issue: Protecting Environmental and Natural Resources

Environmental and Natural Resources. NC State Extension
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. 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.

Adapting microbial enzymes to capture atmospheric carbon and increase biofuel crop yields. Robert Rose
LAID GROUNDWORK FOR SPECIALIZED PLANT BREEDING TO REDUCE ATMOSPHERIC CARBON DIOXIDE: Carbon dioxide released by industrial use of petroleum products is among the greatest contributors to global warming and to the growing climate threats it poses. To help reduce the environmental impact of carbon dioxide in the atmosphere, NC State researchers are developing a method to enhance plants' natural ability to pull carbon dioxide from the environment and convert it into nutrients. In addition to benefiting the environment, this method could increase the growth of biofuel and food crops. Researchers have developed a highly efficient method for testing the effects of various mutations on carbon processing in plants, which will allow them to introduce and test about 100 mutations at a time. They have shared the results of their research through a specialized interest group on strategies for developing biofuel and biomaterials, workshops, and graduate and undergraduate student training.

Keeping afloat in the data deluge: coupling observational data, analytics, and integrated models to propel data-driven biological resources management, Natalie Nelson
DELIVERED INSIGHTS TO ENHANCE DATA-DRIVEN MANAGEMENT OF NATURAL AND AGRICULTURAL RESOURCES: Natural and agricultural systems are increasingly monitored through wide-ranging sensors, including those on satellites and installed in the field. But our ability to collect measurements from natural and agricultural systems has progressed more rapidly than the development of tools and analyses that enable stakeholders to make sense of these ever-growing datasets, creating an urgent need for new approaches to interpreting and managing this data. To meet this need, NC State researchers have collaborated with scientists, regulators, producers, and other stakeholders to analyze diverse environmental and agricultural datasets using methods such as machine learning and statistical modeling. Advantages gained from this research include the creation of a harvest closure forecasting system and accompanying web application for shellfish producers and the creation of various fact sheets to make data analysis tools more accessible. This research was shared through publications,

presentations, and specialized training, benefitting researchers and other stakeholders in natural and agricultural resource management. By empowering researchers and growers to better understand and manage natural resources, this research supports the development of a more robust, data-driven approach to preserving the environment and building a resilient food supply.

Soilless Substrate Engineering, Characterization, and Management in Container Production Systems. Brian Jackson
REDUCED ENVIRONMENTAL IMPACT OF PEAT MOSS HARVESTING BY DEVELOPING ALTERNATIVE SOILLESS GROWING MATERIALS: Soilless systems are used to produce billions of plants across nearly all agricultural plant commodities. For over 60 years, the main substrate (or growing material) used for this purpose has been peat moss. Because extracting peat moss from natural wetland bogs releases carbon and contributes to climate change, the need for alternative substrates has never been higher. To address this need, NC State researchers have developed forest-based biomaterials that can be used as agricultural substrates to replace peat moss. These research efforts have resulted in many collaborative initiatives, publications, presentations, and visits to growers and substrate producers. The results of this research have also been shared with industry and with the general public through trainings, workshops, and trade magazines. Thanks to these efforts, a broad range of specialty crop producers, soilless substrate producers, and the broader public have benefitted from increased access to peat-alternative soil products, allowing them to efficiently produce crops while minimizing negative environmental effects.

Understanding interactions among species, climate change, landscapes, and nutrients in freshwater ecosystems. Brad Taylor
DELIVERED INSIGHTS AND TOOLS FOR SUPPORTING FRESHWATER ECOSYSTEM HEALTH: Evolving and increasingly complex environmental challenges create an urgent need to protect environmental resources by understanding how various plants, animals, and other organisms respond to large-scale changes, including agricultural land use, restoration of agriculturally dominated lands, and climate change. NC State researchers use species diversity surveys, field and lab experiments, and collaborations with ecologists, geneticists, and other specialists to study and develop sustainable solutions to environmental challenges. To date, they have advanced the field of ecology by identifying models that can anticipate the ecosystem consequences of changes in species' communities and developing models to predict territorial spread and competition among species. They have also developed the "nature's chefs" concept, which outlines how species have evolved ways to produce food for other species, or deceive other species into thinking they are providing food, in order to ensure the success of the "chef's" offspring and genes. In addition to enhancing the ability to predict and respond to the effects of environmental change at the species and ecosystem levels, this research lays groundwork for discoveries that may advance culinary and nutritional science and change how humans think about food. For example, they could lead to the production of fruits that taste like meat. Researchers have also provided proof-of-concept for a new method to accelerate the biological recovery of stream-dwelling insects, assess restoration success, and import restoration techniques to freshwater fisheries. These insights were shared through publications in peer-reviewed journals, local and national presentations, public outreach events, and press releases.

Critical Issue: Enhancing Food Safety, Nutrition and Health

Food Safety. 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. 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. 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. 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 specialists are working to establish a Food Safety Extension Network of institutions across the southeast to synergistically advance the science of consumer and retail/food service food safety and share expertise, training, and materials across the Land-grant system. Collaborators include institutions from the southern region.

As a result of Extension's efforts, 20,693 participants increased their knowledge of how to prepare foods, including home food preservation techniques and 22,632 participants increased their knowledge of safe home food handling, preservation, or preparation practices. 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 & Health. NC State Extension
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 Extension programs, over 8,000 adults attended nutrition-related workshops, and 4,500 adults attended health and wellness workshops provided by Extension Family and Consumer Science (FCS) agents. 4,700 adults attended workshops related to cooking, and 2,300 attended food preservation workshops provided by Extension FCS agents. In addition, 18,600 youth participated in nutrition, cooking, and health school enrichment programs, camps, clubs, and outreach activities. Extension Master Food Volunteers donated 1,800 hours of service valued at $54,000; and EFNEP volunteers donated 8,700 hours of service valued at over $260,000.

Advanced Thermal and Continuous Microwave Processing of Foods and Biomaterials. Josip Simunovic
IMPROVED FOOD QUALITY AND SAFETY THROUGH NEW ENERGY-EFFICIENT, MICROWAVE-BASED PROCESSING METHOD: Conventional food processing degrades flavor, color, quality, and nutritional value. To address this problem, NC State researchers worked with international partners to develop a new, energy-efficient microwave heating

technology, followed by packaging into flexible, sterile packaging of diverse sizes. In 2022, two processing facilities employing this technology were constructed and put into operation, one in NC and another in Kenya. Both facilities enhance food safety and quality and reduce greenhouse gas emissions. The Kenyan facility is the first of its kind in Africa, and it is producing shelf-stable products that not only enhance the local economy but also reduce severe childhood nutritional deficiencies and the region's dependence on imported grain during a time of heavy market disruption. In addition to maximizing the preservation of sensitive flavors and nutrients and extending shelf life without refrigeration to 12–18 months at ambient temperatures, this technology minimizes or eliminates food waste and reduces processing time and costs. In the first year of its operation, the NC processing facility has been instrumental in the commercialization of over 70 new food products. This new technology has also led to the publication of 15 articles, 12 book chapters, 16 presentations, 2 US patents, 4 international patents, and a collaboration with South African partners to expand the commercialization of processed sweet potato products in the region. In addition, a larger capacity processing facility is being opened in NC, and more facilities are pending in Africa, South America, and the US.

Flavor and flavor chemistry of dairy products. M Drake
DELIVERED CONSUMER INSIGHTS FOR IMPROVED DAIRY PRODUCTS AND PLANT-BASED DIARY ALTERNATIVES: Consumer demand is increasing for plant-based dairy alternatives (PBDAs) and dairy products with reduced sugar. Pandemic-related consumer motivation shifts have also led to increased demand for food products that offer immune-boosting and calming effects. To meet these demands, NC State researchers conducted studies on consumer insights and the sensory quality of PBDAs, disseminating results to key stakeholders at national and international meetings and in peer-reviewed publications. These studies reveal that consumers prefer yogurt products labeled as "naturally sweetened" over those that emphasize reduced sugar. Honey was preferred over other sweeteners, followed by agave nectar and cane sugar. Yogurt sweetened with sugar was preferred, and yogurt sweetened with Stevia was the least preferred. These studies reveal that taste remains the driving force for consumer preference, and the use of a natural low-calorie sweetener that delivers the sensory experience of sugar is more important than familiarity with the sweetener. An online consumer survey and focus groups revealed that 48% of consumers associate cultured dairy products with immune health, 69% associate ice cream with calming properties, and creaminess is the key attribute missing in non-dairy immune boosting and calming products. This research reveals important opportunities for industry to better satisfy consumers' needs. Researchers also created and validated a standardized tool for characterizing differences between PBDAs and dairy products, including PBDA's lack of textural smoothness and the presence of unique plant-based flavor profiles. Product developers can use these insights to develop and evaluate PBDAs with desirable tastes and textures.

Implementation of CRISPR-based technologies in food bacteria. Rodolphe Barrangou
ADVANCED GENE EDITING OF BENEFICIAL BACTERIA TO IMPROVE FOOD SECURITY AND HUMAN HEALTH: Bacteria play important roles in various habitats, and they have been studied extensively given their roles in human health and disease. A diversity of bacteria are used throughout the food supply chain and as dietary supplements. To better understand and enhance the safety and efficacy of beneficial bacteria and support development of a more robust food supply, NC State researchers are developing and using CRISPR-based gene editing technologies to study and modify bacterial strains. These efforts include the development of novel technologies that enable genetic manipulation of food microbes for use in fermentation and as probiotics, collaborations with industry and academia to commercialize new technologies and products, and training the next generation of scientists for fruitful careers in food, biotech, and agriculture. Researchers have published 18 manuscripts in the scientific literature and given

over 60 talks and technical presentations at seminars and scientific conferences. They have also collaborated with start-up companies and industrial partners to support new product and biotech start-up launches, advance plant and crop breeding techniques, secure new patents, create novel clinical therapies, and much more, with a focus on fostering a healthier, more secure population and planet.

Sensory and Chemical Characterization of Green and Roasted Coffee as a Means of Improving Coffee Shelf Life and Understanding Potential Health Effects. Gabriel Harris
ENHANCED COFFEE PRODUCT QUALITY AND KNOWLEDGE OF COFFEE'S HEALTH BENEFITS: Coffee is the third most widely consumed beverage worldwide, and consumers are becoming increasingly aware of the quality, sustainability, and health issues surrounding the coffee they drink. Coffee consumption has also been associated with a decreased risk of chronic disease, including type II diabetes. To enhance the quality of coffee products, NC State researchers have invented and are pursuing a patent for a new process for infusing fruit flavors and nutrients into coffee beverages. They have also demonstrated the effectiveness of a new microwave coffee extraction method and begun investigating sustainable, low-water-use methods of coffee production. In addition, researchers have completed a clinical trial and are preparing a manuscript on the effects of coffee on blood sugar regulation, and they completed a joint clinical trial with Elon University examining the effects of coffee and coffee roasting methods on athletic performance. This research has led to 2 peer-reviewed papers and an invention disclosure, delivering insights and methods that will benefit not only industry but also consumers in general.

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

4-H Youth Development. NC State Extension
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 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. 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. 188,245 youth in North Carolina participated in one or more 4-H youth development programs during 2022. 4-H clubs had 19,585 members. 1,149 youth participated in overnight camping programs, 137,415 youth participated in school enrichment programs, and 46,788 youth participated in special interest programs.

Insect-Specific Target Systems for the Development of Novel Tools for Cockroach Control. Coby Schal
LAID GROUNDWORK FOR MORE EFFECTIVE PEST CONTROL OF BED BUGS AND COCKROACHES: Bed bugs and cockroaches have been shown to adversely affect human health, causing allergic reactions, contamination, and psychological distress. Bed bugs are now also emerging as significant parasites affecting poultry farms. NC State researchers have discovered insights into potential new approaches to controlling these pests. They discovered that cockroaches are highly susceptible to fungal infections, they analyzed bed bug production of histamine (a substance that provokes immune system reactions) to better understand the health risks associated with histamine and support potential mitigation approaches, and they discovered particular drugs and drug classes that have great potential for controlling bed bug infestations in poultry farms. In addition, they found evidence that the use of bed nets to prevent

bed bug infestation is likely ill-advised because it may contribute to the development of insecticide resistance. They also developed a deeper understanding of why cockroaches rapidly evolve high levels of resistance to some insecticides and not others, laying groundwork for more effective management of these pests. These findings benefit researchers, the pest control industry, public sector regulators, and communities coping with cockroach and bed bug infestations.

Using a Consumption-Oriented Supply Chain Analysis to Increase Consumer Access to Local Food. Jessica Bloom

DEVELOPED AND DEPLOYED DATA-DRIVEN APPROACHES TO STRENGTHENING LOCAL FOOD SYSTEMS: According to Feeding America, 1 in 8 people in NC face food insecurity, which is linked to negative health outcomes in adults and children. In addition to benefitting the public by increasing access to affordable, healthy food, local food systems are an important economic resilience strategy, particularly for small to mid-sized farmers. To strengthen local food systems, NC State researchers work closely with Extension, delivering data-driven models, programs, and formalized training that helps connect consumers to these local food sources. In 2022, NC State research assisted Extension in training volunteers to provide 1,922 service hours valued at $57,564. In addition, 5 counties launched the Donation Station program, and 2 counties continued the program from 2021, providing healthy local food and nutrition education to local food-insecure families. These collaborative efforts have also resulted in local food education and assistance outreach to 1,164 children and families across 21 counties. To expand on these successes, researchers are currently developing local food purchasing models in 4 counties to improve farmer profitability, increase access to healthy, local food, create a culture of health and wellness, and promote community collaboration and skill sharing.