

The Cornell Agricultural Systems Testbed and Demonstration site (CAST) for the Farm of the Future

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Keywords: PLF, testbed, demonstration site, validation, data integration, analytics

Implications

The Cornell Agricultural Systems Testbed and Demonstration site (CAST) for the Farm of the Future is a testbed and demonstration site for data-driven technologies and management practices where coordinated technology development, testing, demonstration, systematic integration of data, and exchanges of physical materials and ideas are shaping the Farm of the Future. CAST is a cluster of three farms in NY State that hosts data-driven research, extension, and education for crops and dairy production under the aegis of the Cornell Institute for Digital Agriculture. CAST advances climate-smart data-driven solutions for food systems, integrating commercially available and in-the-pipeline technologies and transformative practices.

Introduction

US and global agriculture face challenges in sustainability, productivity, profitability, environmental integrity, resilience, rural prosperity, and inclusiveness. Few technologies are well tested, making their selection and incorporation into the farm suite difficult. Data-driven technologies that might address farming challenges are proliferating, but in a haphazard and disconnected manner. The massive streams of data and frequent reports or alerts generated by today's agricultural data systems, all running unique software and producing data in disparate formats, overwhelm farm personnel (Hansen et al., 2020). The Farm of the Future (**FotF**) requires research-based insights to resolve these and related problems. To this end, the Cornell Agricultural Systems Testbed and Demonstration Site (**CAST**), is a networked cluster of test farms with associated facilities and personnel that leverages the resources of Cornell and its industry and academic partners to conduct data-driven research, extension, and education to advance data-driven technology and management practices for supporting crop and dairy production for the FotF.

CAST scope and overarching goals

CAST seeks to advance, evaluate, and demonstrate data-driven solutions for dairy farming. A multidisciplinary team of researchers, extension specialists, and educators from Cornell University and the University of Arkansas at Pine Bluff are undertaking a systems-based approach to research, extension, and education, focusing on the field-crop and dairy sectors.

Research at CAST focuses on scientific groundwork for innovation, evaluation, and demonstration of data-driven technology and management practices. A specific objective is demonstrating the value of integrating existing and emerging data-driven technologies and practices under commercial-farm-like conditions. Thus, CAST's farming ecosystem supports integration and testing of commercially available technologies and development, deployment, and testing of technologies in the research pipeline. Research is organized under four thrust areas: (1) innovation in technology and farm practices, (2) data integration, (3) data analytics and decision support, and (4) impact assessment.

Extension efforts focus on developing the CAST Network for Extension and Teaching. This network involves farmers, manufacturers, consultants, academic experts, and others in every stage of problem identification, planning, implementation, evaluation, and feedback. CAST-NET provides insights about cutting-edge technology goals and actively supports adoption. To promote adoption of innovations developed and demonstrated at CAST, access to in-person and virtual demonstrations is available. Education efforts at CAST's cluster of working farms are centered on providing experiential learning opportunities including creation, experimentation, and experiences in the development, delivery, and evaluation of data-driven technologies and management practices. CAST leverages existing programs and creates new educational initiatives including a minor and courses in Digital Agriculture. CAST engages students in research, outreach, and science communication providing real-world, hands-on educational experiences to the next generation of agricultural leaders, scientists, and professionals.

CAST infrastructure capacity building

The testbed and demonstration site comprises a cluster of 3 farms operated by Cornell University: the Cornell University Ruminant Center, Cornell Teaching Dairy Barn, and Musgrave Research farm. Infrastructure available for research, outreach and educational efforts at CAST include data-driven tools and equipment for high-throughput phenotyping of cow behavior, physiological, and performance parameters, and high throughput phenotyping of soil, crops, air, and water. Technologies for livestock related activities include wearable and non-wearable automated cow features, behavior, physiology, and performance monitoring systems for individual cows and groups (e.g., rumination time, eating time, feed intake, water intake, feeding management, physical activity, body temperature, lying behavior, body weight, milk yield, milk conductivity, and milk components) and semi-automated systems conduct spot measurements of methane, carbon dioxide, oxygen, and hydrogen from individual cows. Computer vision systems automate monitoring of locomotion score and body condition and monitor feeding management and behavior of cow groups. Barn air monitoring sensors monitor green-house gases, volatile organic compounds, and particulate matter. Crop and nutrient monitoring

technologies include yield monitoring sensors for forages and grains, field weather stations, and FTIR sensors for estimations of manure gas production.

Development, refinement, and demonstration of data-driven technologies and management practices at CAST

Examples of experiments and studies enabled by CAST infrastructure and personnel include validation and demonstration of computer vision systems for locomotion and body condition scoring of dairy cattle, refinement and demonstration of point-of-care diagnostic systems for pregnancy and ovarian status determination in cattle, development and prototype testing of virtual fencing systems for cattle, development of machine learning algorithms for predicting cattle health, estimation of individual cow feed intake using wearable sensors, testing automated systems for in-line milk sample collection and milk feature monitoring, estimation of whole-herd and whole-farm environmental footprint, characterization of manure lagoon methane emissions using FTIR sensing, and testing effects of herd and manure management practices on barn level ammonia concentrations for calibration of ammonia emissions in the RuFaS (Ruminant Farming Systems) model (Hansen et al., 2021). Examples of dairy relevant crop research include variable application rates of crop inputs (e.g., variable seed rate application across management zones, variable rate application of biochar, interseeding of cover crops in corn using an autonomous robot), single-strip spatial evaluation approach using unmanned aerial vehicles, on-farm weather forecasting and satellite imagery, and integrating microenvironment sensors for cover crops.

Data integration and analytics

A network of hardware and software infrastructure aggregates data from CAST farm operations. A series of Postgres databases and associated web applications integrates automatically or semiautomatically cropping data including soil maps, satellite imagery, drone, forage and grain yields, and digitized data of cropping activities and manure application. Similar data integration frameworks and web applications collect dairy cattle data including individual cow and herd performance, health, reproduction, behavior, and physiological data generated by numerous wearable and non-wearable sensor systems and on-farm dairy herd management software tools. Joint databases of crop and animal raw data are fully integrated automatically and in real time for predictive analytics and data summarization and reporting including farm, field, herd, and cow level performance, health, and environmental impacts.

Industry partnerships at CAST

A mission of CAST is to foster partnerships and collaborations with diverse agricultural technology developers and providers, including start-up companies and established providers of technology to the agricultural sector. CAST offers industry partners unique infrastructure and human capital to facilitate the development, refinement, testing, and demonstration of technological innovations and data-driven best management practices. This framework offers partners different levels of access to CAST infrastructure and intellectual property, resources, and outputs through a partnership and collaboration program. CAST established partnerships with +15 domestic and international companies including providers of technology for crops and dairy production systems.

Education, training, and professional development at CAST

Graduate and undergraduate students are involved in research, extension, or educational activities at or enabled by CAST. Crossdisciplinary training of students and personnel in many aspects of agricultural production, data science, engineering, computer science, plant science, agronomy, animal and veterinary science, sociology, economics, and agricultural communication are provided. Through research opportunities, internship, a minor in Digital Agriculture, and related courses, Cornell and non-Cornell students learn and gain experience in multiple aspects of row crop and dairy production systems, engineering and design of automated tools for crop and cattle management, development and optimization of biomarker assays systems, integration of data-driven tools and equipment for farm management, and development, testing, and implementation of software tools for data aggregation and advanced analytics.

Conclusions

The Farm of the Future must be shaped by research-based insights if it is to sustainably achieve climate-change mitigation, environmental integrity, and other key sustainability goals. CAST is a cluster of three farms in NY State that hosts data-driven research, extension, and education to advance data-driven solutions for dairy production systems, integrating both commercially available and in-the-pipeline technologies and transformative practices. A stakeholder network, the CAST Network for Extension and Teaching, involves farmers, manufacturers, consultants, academic experts, and others in problem identification, planning, implementation, and evaluation. Educational programing including a minor, courses, and internships provide opportunities for experiential learning to students.

Acknowledgements

Research supported by the USDA National Institute of Food and Agriculture (NIFA) Farm of the Future project # 2023-77038-38865 and by the National Science Foundation Directorate for Computer and Information Science and Engineering Project IIS-2211941.

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